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AN OXYGEN ENRICHED AIR SYSTEM FOR THE AV-8A HARRIER

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Breathing Regulator

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Due to the high support costs, increase in aircraft down time and hazards associated with the utilization of liquid oxygen, development has been progressing with On-Board Oxygen Generation Systems (OBOGS) which have the capability of providing an aviator's breathing gas of sufficient quality and quantity. An Oxygen Enriched Air System (OEAS), employing the molecular sieve concept, has been subjected to environmental test and evaluation by the Naval Air Development Center. The OEAS contains a molecular sieve oxygen concentrator, breathing regulator and performance monitor. The test and evaluation program was conducted to verify that design criteria have been met and to establish system performance in the environments

anticipated on the AV-8A "Harrier" and other tactical aircraft. The system has successfully demonstrated the ability, under certain conditions, to provide a breathing gas composed of 95 percent oxygen and 5 percent argon. It will also provide adequate amounts of breathing gas and sufficient oxygen concentrations for a one or two man open loop breathing schedule. Concentrator anomalies have occurred during the program with control electronics and lubricants within the unit. Redesign of the breathing regulator is necessary to insure compatibility with lox systems and in providing a greater gas quantity during ground idle conditions. Redesign of the performance monitor is necessary to withstand environmental conditions anticipated in service use. Prior to future aircraft incorporation, design studies must pay consideration not only to bleed air pressure availabilities, but also to temperatures which may degrade system performance.

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SUMMARY

Due to the high support costs, increase in aircraft down time and hazards associated with the utilization of liquid oxygen, development has been progressing with On-Board Oxygen Generation Systems (OBOGS) which have the capability of providing an aviator's breathing gas of sufficient quality and quantity. An Oxygen Enriched Air System (OEAS), employing the molecular sieve concept, has been subjected to environmental test and evaluation by the Naval Air Development Center. The OEAS contains a molecular sieve oxygen concentrator, breathing regulator and performance monitor. The test and evaluation program was conducted to verify that design criteria have been met and to establish system performance in the environments anticipated on the AV-8A "Harrier" and other tactical aircraft. The system has successfully demonstrated the ability, under certain conditions, to provide a breathing gas composed of 95 percent oxygen and 5 percent argon. It will also provide adequate amounts of breathing gas and sufficient oxygen concentrations for a one or two man open loop breathing schedule. Concentrator anomalies have occurred during the program with control electronics and lubricants within the unit. Redesign of the breathing regulator is necessary to insure compatibility with lox systems and in providing a greater gas quantity during ground idle conditions. Redesign of the performance monitor is necessary to withstand environmental conditions anticipated in service use. Prior to future aircraft incorporation, design studies must pay consideration not only to bleed air pressure availabilities, but also to temperatures which may degrade system performance.

ACKNOWLEDGMENT

The author wishes to express appreciation to James Nycum, John Jenkins and William Daymon, all of the Environmental Branch of the Technical Support Directorate for their assistance in test procedures and equipment operation. Special thanks also goes out to Donald Harris of the Systems Engineering Test Directorate, Naval Air Test Center, for his assistance with environmental parameters anticipated in flight and aircraft installation.

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INTRODUCTION

Development has been progressing on On-Board Oxygen Generation Systems (OBOGS) which have the capability of meeting the physiological requirements of a one or two man open loop breathing schedule. The utilization of such a system will result in safer operating conditions due to the removal of liquid oxygen (lox) and its associated handling and storage hazards, improved efficiency with reduced aircraft down time, and substantial space and dollar savings resulting from the elimination of generation and storage equipment required by lox systems. With the evolution of vertical/short takeoff and landing (V/STOL) aircraft, deployment on board non-aviation (amphibious assault) ships without lox services and independent of carrier or shore base support is greater realized with incorporation of an OBOG system. The ultimate Navy objective is incorporation of OBOGS in all high performance tactical aircraft.

Early investigations under a joint Navy/Air Force development program dealt with systems capable of generating 99.5% oxygen. A fluomine sorbent process of chemical adsorption/desorption through cyclic variation of pressure and temperature, and water electrolysis were initially explored as viable generation methods. Parallel to this effort, the Navy had also investigated, under the sponsorship of the Naval Air Systems Command (AIR-340B and AIR-531), the molecular sieve concept of adsorption/desorption of nitrogen from pressurized air. All three systems were subjected to functional and environmental testing at the Naval Air Development Center. The fluomine and molecular sieve systems successfully passed this phase of the program and were subsequently flight tested on board an EXCAP EA-6B "Prowler" at the Naval Air Test Center under the auspices of the Pacific Missile Test Center. Although providing a breathing gas containing a maximum of 94-95% oxygen, the decision was made by the Navy to pursue the molecular sieve concept which showed tremendous advantages in system simplicity, weight, resources required, and aircraft modification/installation. The concept has also been proven physiologically acceptable under extensive 'man rating' tests conducted by the Naval Aeromedical Research Laboratory and Air Force School of Aerospace Medicine.

An Oxygen Enriched Air System (OEAS), employing the molecular sieve concept, has been developed, under the sponsorship of AIR-531, for incorporation on board the AV-8A 'Harrier'. The Harrier (Figure 1) is a single cockpit, tactical fighter, the first in the V/STOL generation of aircraft currently operational. An AV-8A has been modified for OEAS incorporation with subsequent Technical Evaluation conducted by the Naval Air Test Center. A six month Operational Evaluation with six OEAS incorporated aircraft will follow.

The purpose of this report is to document developmental/qualification testing of the Oxygen Enriched Air System. The tests, conducted in the Environmental Test Facilities of the Naval Air Development Center, Naval Air Test Center, and Dayton T. Brown, Inc., were made in order to verify that design criteria have been met and that the components of the OEAS will not present any hazard to personnel and/or aircraft while in operation.

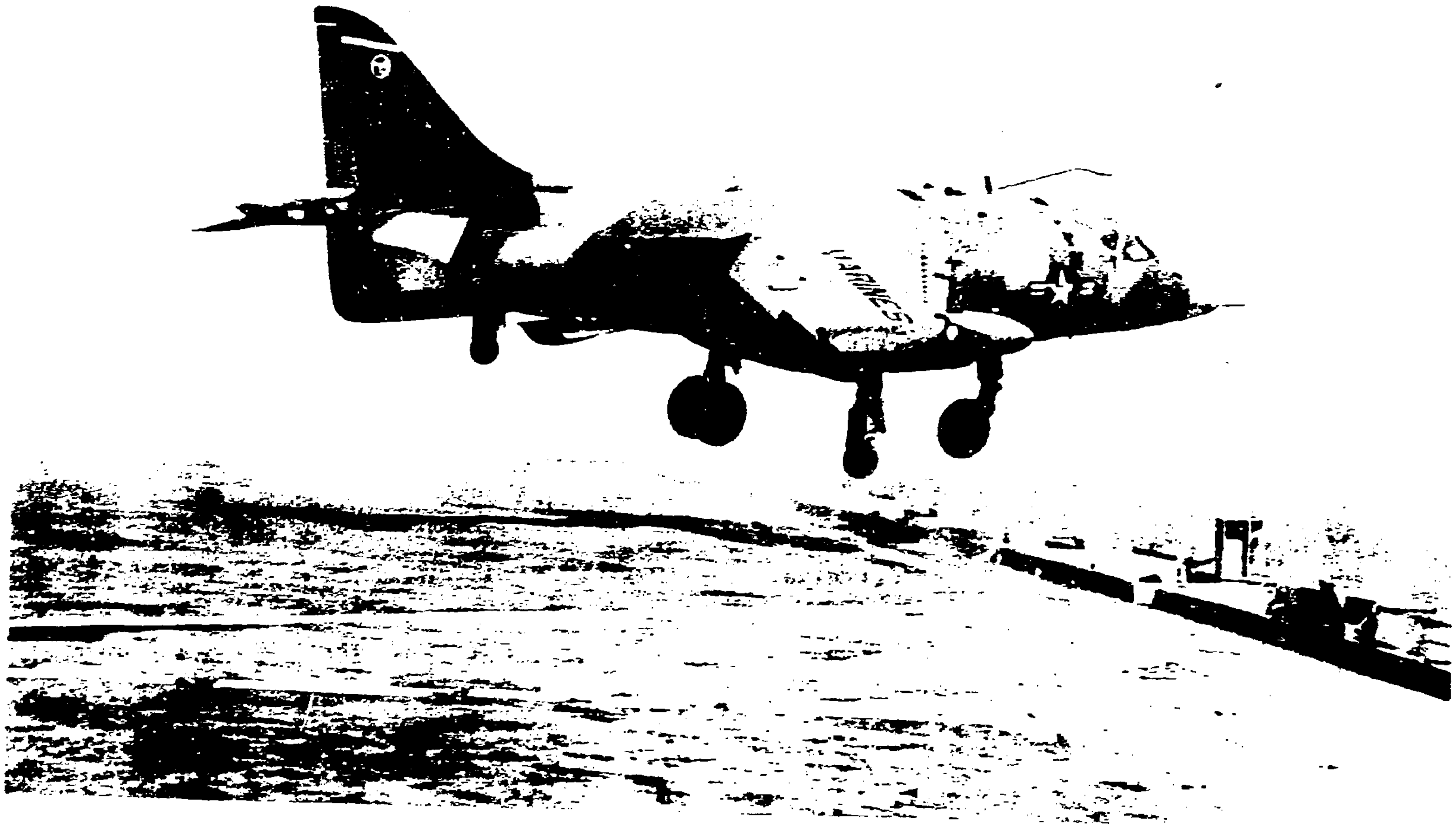


Figure 1 — The AV-8A Harrier

OXYGEN ENRICHED AIR SYSTEM (OEAS) DESCRIPTION

The Oxygen Enriched Air System (OEAS) is an on board aircraft, self-contained system which provides an oxygen enriched breathing gas to the aircrewman. The OEAS was manufactured by the Bendix Corporation, Instruments and Life Support Division, Davenport, Iowa, under NAVAIRDEVCEN contract N62269-78-C-0128. The system consists of three components – Molecular Sieve Oxygen Concentrator, Breathing Regulator, and Performance Monitor. Figure 2 below shows a simplified schematic of how the OEAS functions when installed in the Harrier aircraft. Compressed engine bleed air from the 8th stage manifold is passed through a heat exchanger to the Molecular Sieve Oxygen Concentrator. The oxygen enriched output then passes through the existing aircraft tubing to the aircraft mounted Breathing Regulator, then to the mask. A sample of the breathing gas is supplied to the partial pressure oxygen sensor (Performance Monitor) to monitor the gas and provide a warning signal when oxygen concentration falls, approaching minimum physiological requirements. A detailed description of all components is presented in the sections that follow.

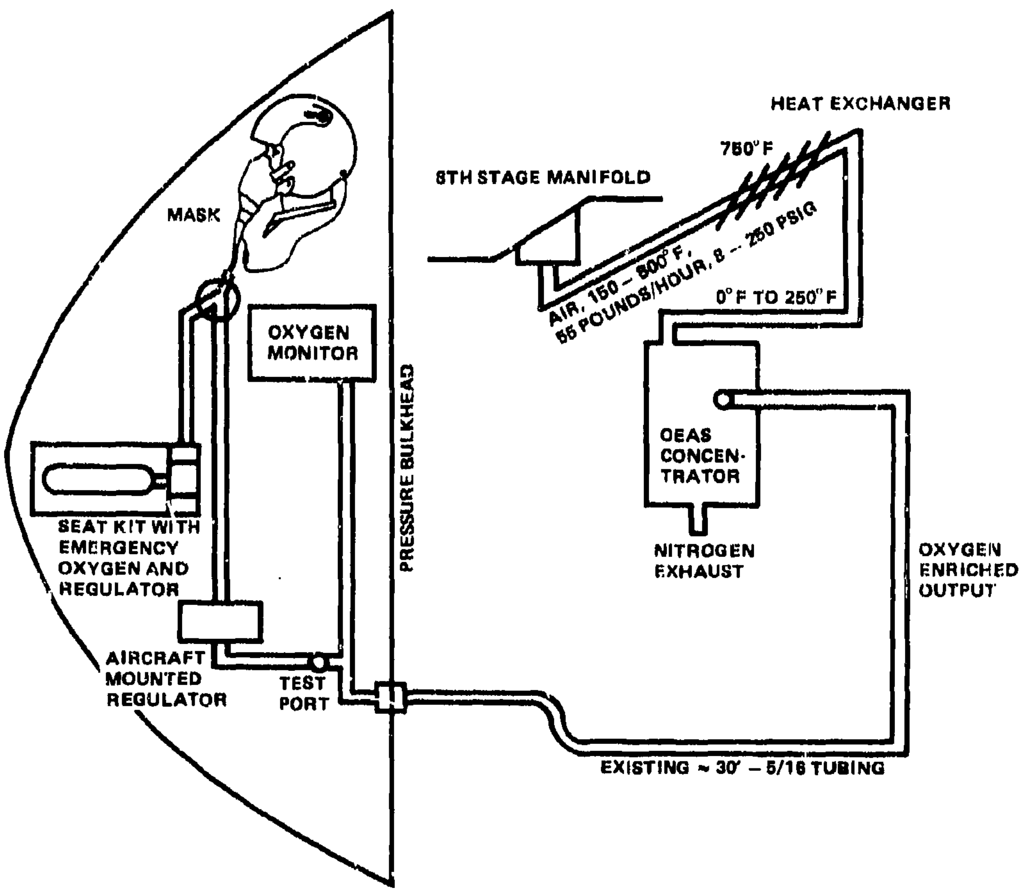


Figure 2 – Tne On Board Oxygen Generation System for AV8A Aircraft

OEAS MOLECULAR SIEVE OXYGEN CONCENTRATOR

The molecular sieve oxygen concentrator, P/N 3261009-0105, (Figures 3, 4, 5, 6) is a self-contained unit, capable of providing the breathing supply requirements for a one man open loop breathing schedule. Designed for direct replacement of a 5 liter lox converter, the unit has dimensions of 12.97 in. wide by 10.2 in. high by 10.7 in. deep and weighs 41 pounds. An overall size comparison of the unit with 5 and 10 liter lox converters is presented in Figure 7.

The unit contains 2 beds, each containing approximately 11 pounds of crystalline alumino-silicate pellets (Figure 8) containing pores 5A in diameter. Nitrogen molecules are preferentially absorbed by the pellets from a pressurized process airstream, leaving the effluent gas enriched in oxygen and argon. Since the adsorption process retains molecules by strong physical forces rather than chemical bonding, no heating or cooling is required for oxygen concentration. The pressure swing cycle, whereby the beds are alternately pressurized and purged to ambient pressure provides the driving mechanism for the adsorption and desorption processes. When the adsorbed nitrogen is desorbed by reduction in pressure, it leaves the crystal in the same chemical state as when it entered, so the adsorption and desorption processes are considered completely reversible.

Referring to the system schematic of Figure 9, pressurized air (8 to 250 psig, 0 to 250°F.) is admitted to the beds via the following:

Air Heater: Two resistance heaters are employed as part of the thermal control system, required for delivery of adequate oxygen concentrations during operation with low ambient and inlet air temperatures. This system is necessary, as low temperature adversely effects unit performance due to changes in adsorption capacity and nitrogen/oxygen selectivity. The thermal control system also employs, as presented in the schematic of Figure 10, an air temperature sensor and a temperature sensor, second temperature controller, solenoid valve, and heated air diffuser for control of air temperature inside the insulating shroud (a release of approximately 25 lpm of heated air). The inlet air heater will maintain a constant inlet air temperature (to the beds) of 110-115°F. An inlet air temperature of 75-80°F will require intermittent operation of heater 1 only, while an inlet air temperature of 0°F will require full operation of both heaters. Designed to operate when supplied with 18-29 VDC in accordance with MIL-STD-704B(20), maximum air heater power consumption is 616.5 watts (10.63 amps for each heater at 29 VDC).

Air Filter: A coalescing filter is incorporated for removal of both particulate matter and liquids including aerosol mist particles. Liquid and/or mist will be drained immediately through a bleed port in the bottom of the filter housing. Particulate matter will remain entrained in the filter cartridge.

Pressure Reducer: A pressure reducer is included to limit air consumption, which increases with pressure, and to prevent excessive pressures to the beds, unit plenum/plumbing, and breathing regulator. The reducer will begin regulating at an inlet pressure of 25 psig and reduce linerally until outlet (bed inlet) pressure is 67 psig with an inlet of 250 psig.

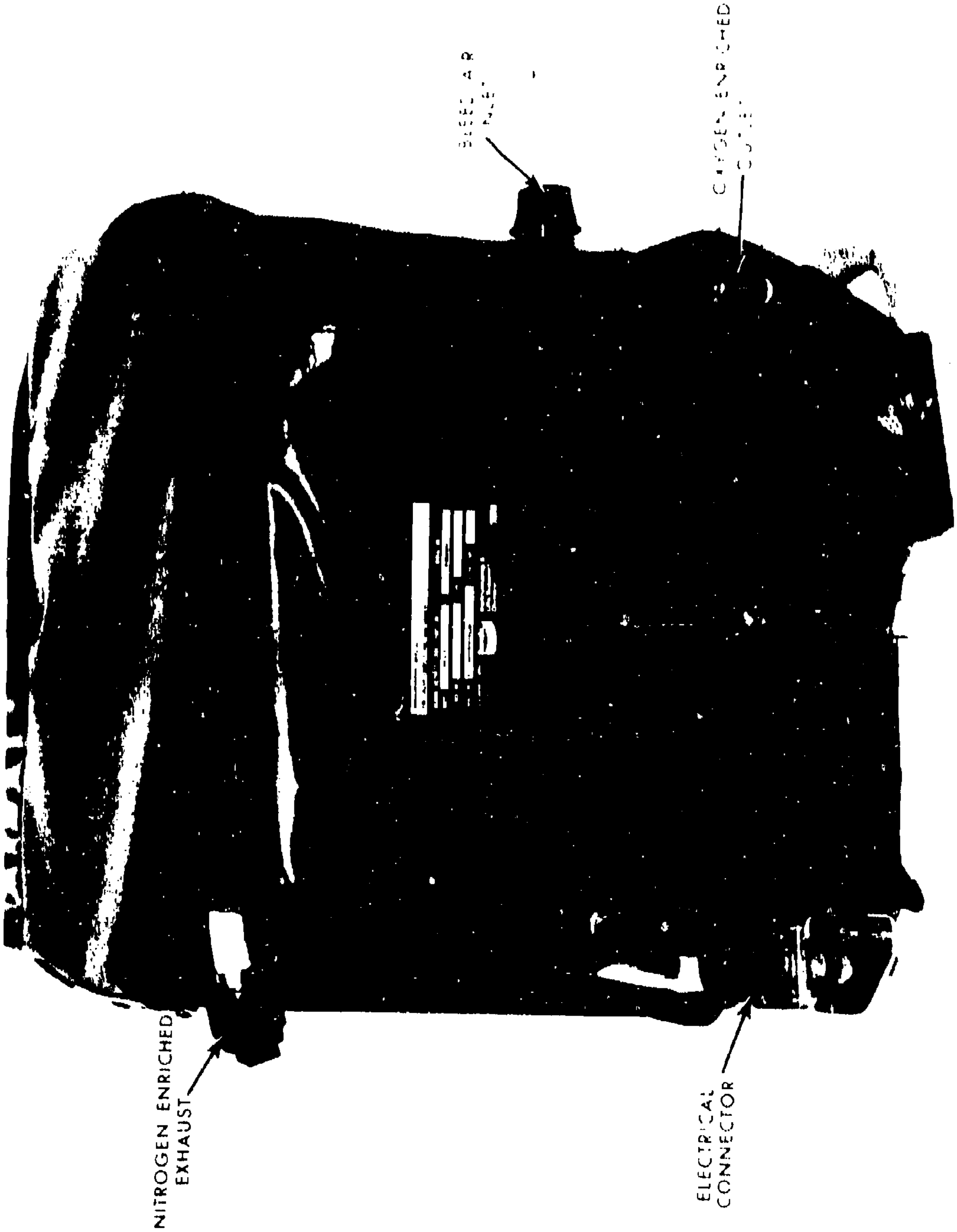


Figure 3 — The Molecular Sieve Oxygen Concentrator (Front View)

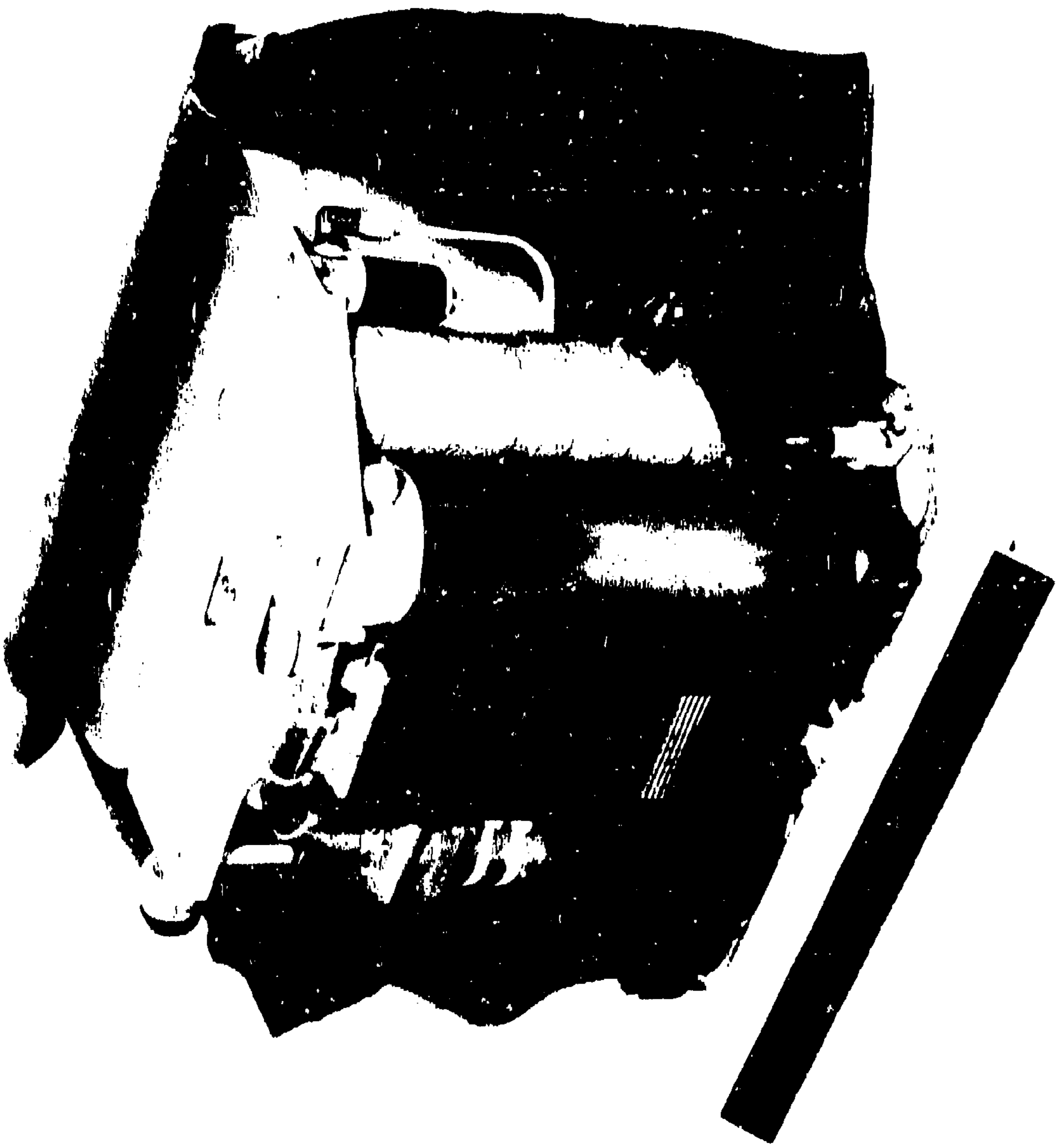


Figure 4 – Molecular Sieve Oxygen Concentrator (Shroud Removed)

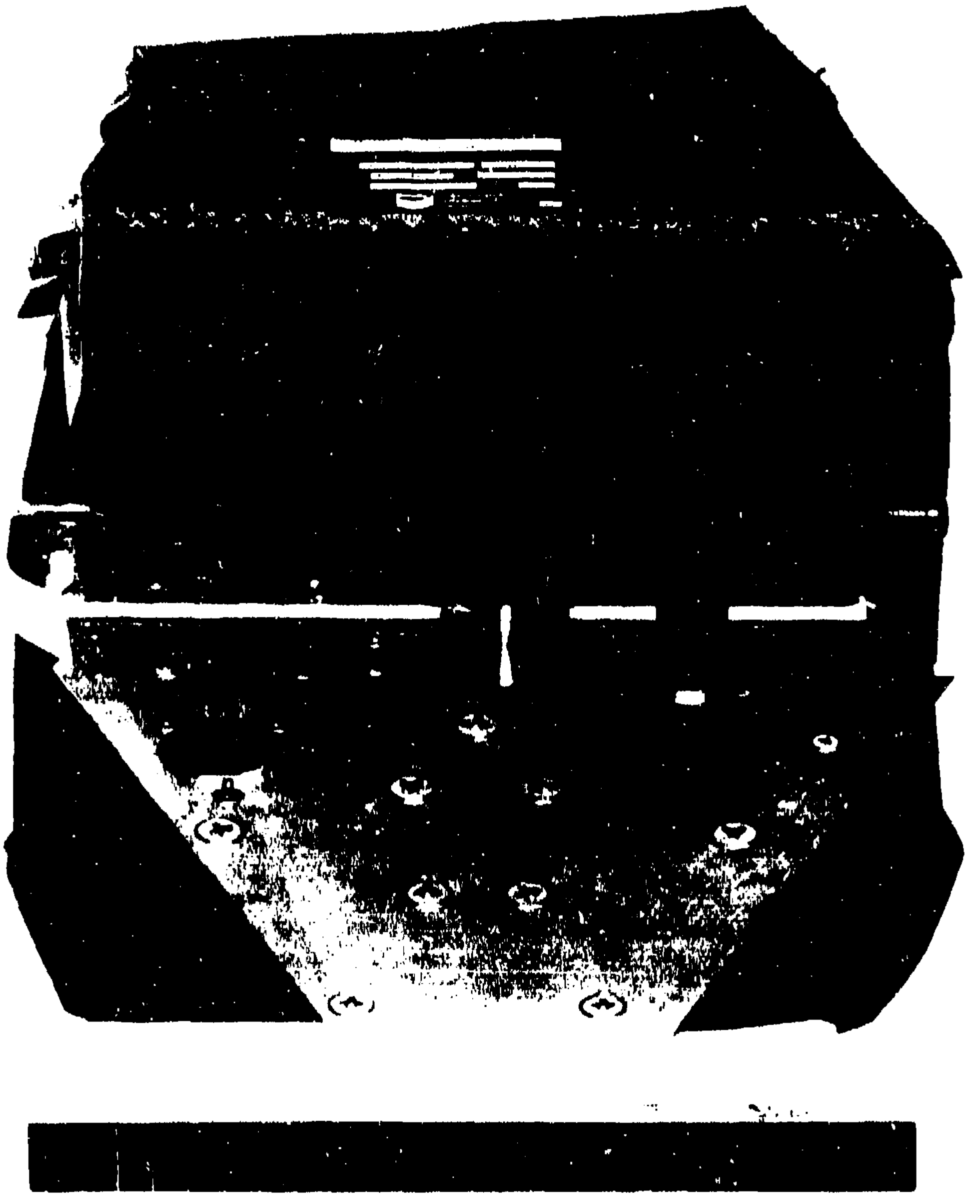


Figure 5 – Molecular Sieve Oxygen Concentrator (Bottom View)

Figure 6 – Molecular Sieve Oxygen Concentrator (Top View)

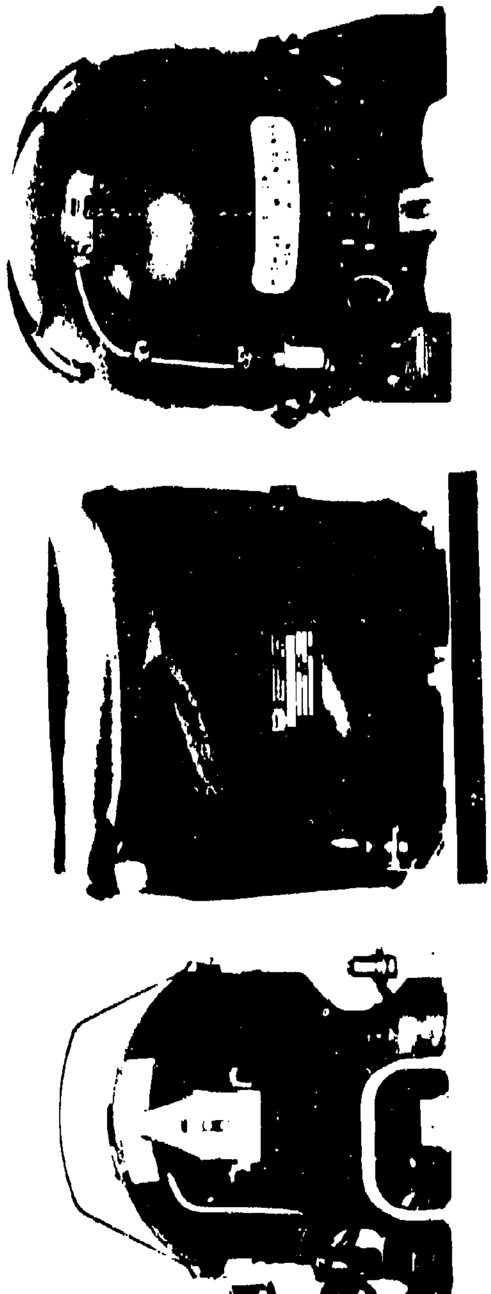


Figure 7 — OEAS Concentrator and 5 and 10 Liter Lox Converters

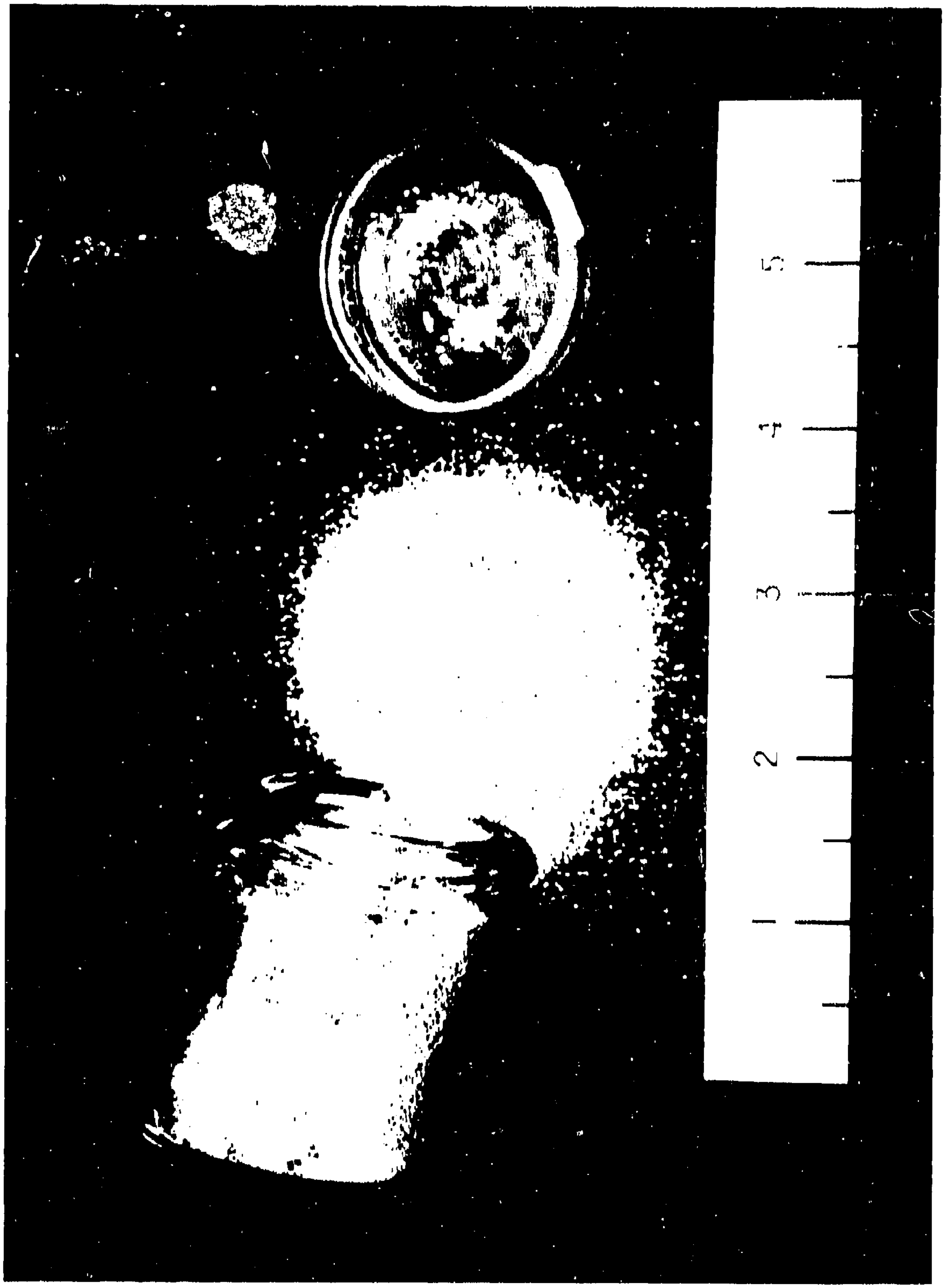


Figure 8 — Molecular Sieve Pellets

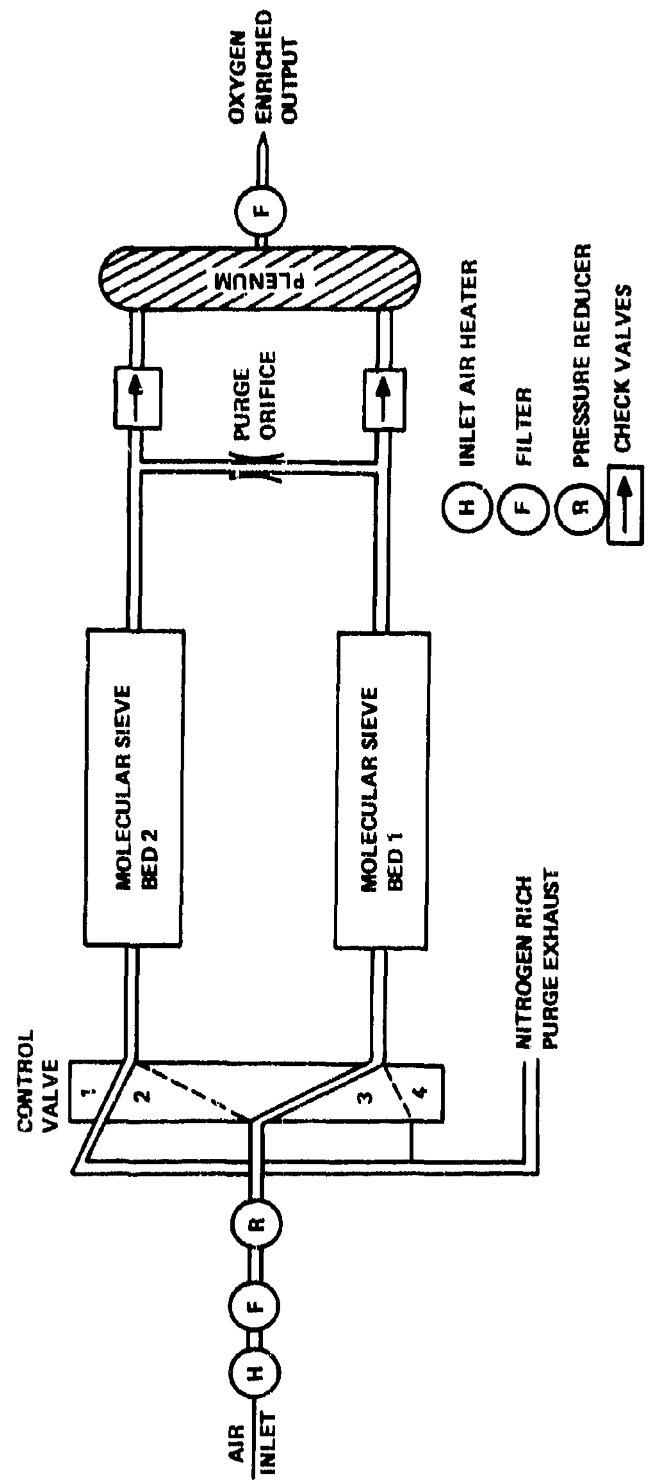


Figure 9 — Molecular Sieve Oxygen Concentrator Schematic

Control Valve: The rotary control valve rotates continuously in one direction during operation and cycles or alternates the adsorption and desorption processes in the two molecular sieve beds. The rotary valve consists of a contoured rotating disk and a ported stationary disk both inside the main valve housing. The motor-reduction gearhead output shaft drives the rotating valve disk at a constant speed of 6 revolutions/minute. The rotating disk slides on the stationary disk to port the inlet air to the pressurized bed and simultaneously vent the other bed to ambient pressure. With a constant speed of 6 rpm, a nitrogen enriched bed purge occurs once every 5 seconds. The drive motor operates from nominal 400 cycle power provided by an integral inverter which operates with 18 to 29 volts DC. The drive motor, control electronics and solenoid are all on the same circuit.

A pressure relief valve is also included in the rotary valve housing to protect the beds, plenum and breathing regulator from excessive pressure in the event of reducer failure. The relief valve has a crack pressure of 78.5 psig and a fully open pressure of 87 psig.

The flow from the pressurized molecular sieve bed during adsorption passes through a check valve into the plenum (approximately one liter volume) and out through a 0.5 micron filter as an oxygen enriched product. A portion of the product gas is passed through a purge orifice (that drops the pressure) and into the downstream end of the second bed for regeneration.

OEAS BREATHING REGULATOR

The OEAS Breathing Regulator, P/N 3260014-0201, is presented in Figure 11. The need for a special breathing regulator as an integral part of the OEAS has arisen due to (1) changes in the positive pressure breathing schedule required to maintain the alveolar oxygen partial pressure at physiologically acceptable levels due to the use of 94-95 in lieu of 100% oxygen and (2) regulator supply pressures are typically lower than the 40 psig minimum required by standard miniature regulators. The regulator is an automatic, pressure breathing type which provides, on demand, breathing gas to the A-13A mask (or equivalent). The main feature incorporated (Figure 12) within the aluminum alloy body is a balance demand valve coupled with a large area breathing diaphragm for operation with low inlet pressure. Designed to operate with a minimum inlet pressure of 5 psig at sea level and 15 psig at 30,000 feet or above, outlet pressures will fall within the limits presented in Figure 13, which shows the deviation with positive pressure breathing supplied by standard 100% oxygen chest mounted (miniature) regulators. Outlet flow is limited to 50 lpm at 5 psig and 80 lpm at 10 psig. Flows exceeding these values will result in negative (suction) pressures in the mask.

The regulator was initially designed for chest mounting on the MA-2 torso harness or SV-2 survival vest, used in conjunction with East/West Industries mounting bracket assembly kit 237C100-3. From Figure 14 it can be seen that the 9 ounce OEAS regulator (3.8 in. x 2.8 in. x 1.7 in.) is similar to the Bendix Type 3260002-0301 Diluter Demand Regulator (right) presently used on the AV-8A with respect to volume, inlet/outlet ports and mounting configuration. Since the rerouting of standard breathing gas supply lines with aircraft modification (to be discussed later), the regulator is now airframe mounted. While the basic design of the regulator remains intact, modifications were made to both the aneroid assembly and mounting bracket to withstand the vibration environment anticipated. Outlet pressures were also raised in order to overcome the pressure drop associated with the personnel hose assembly and still fall within the limits of Figure 13.

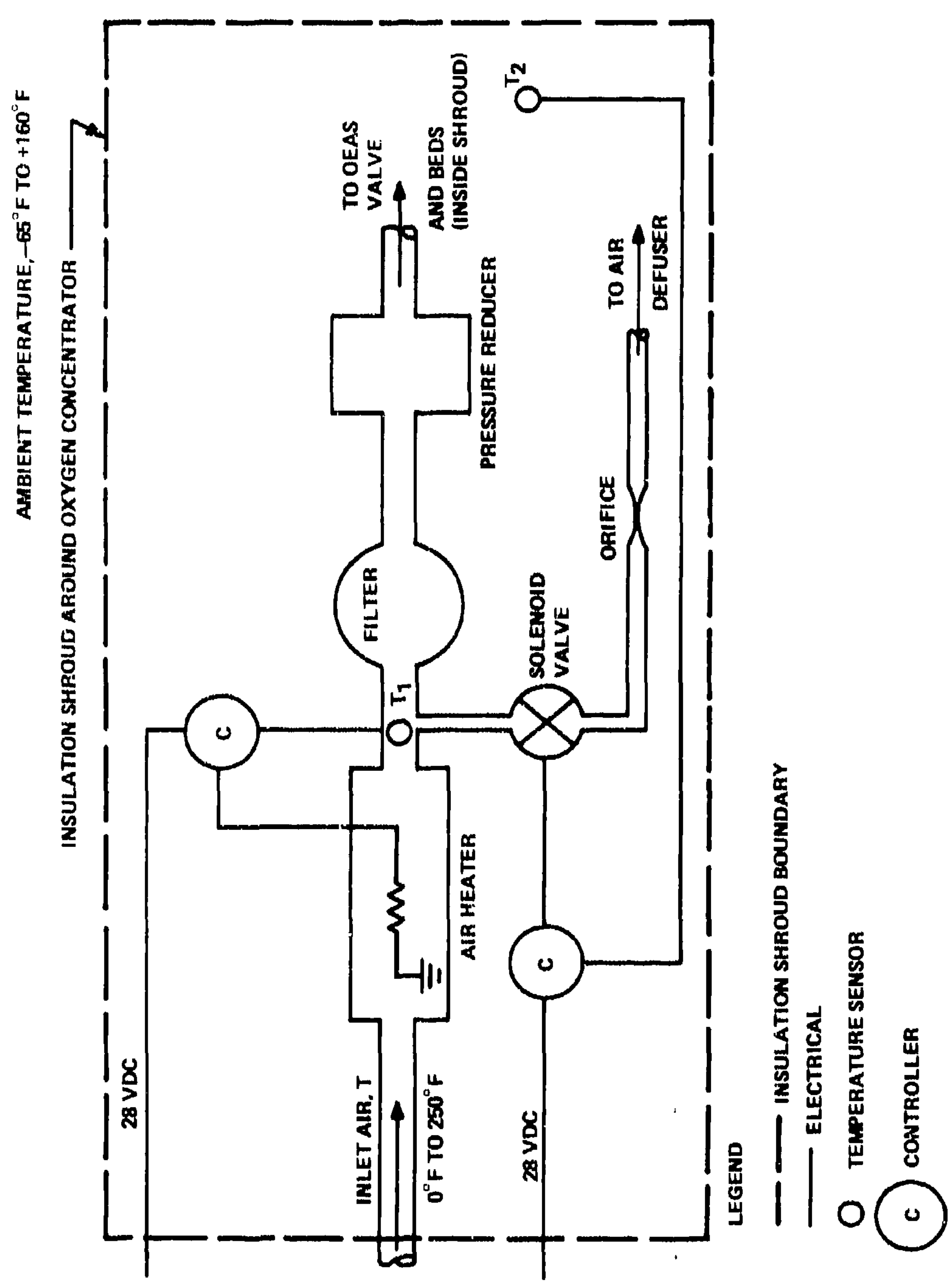


Figure 10 – Thermal Control System Schematic

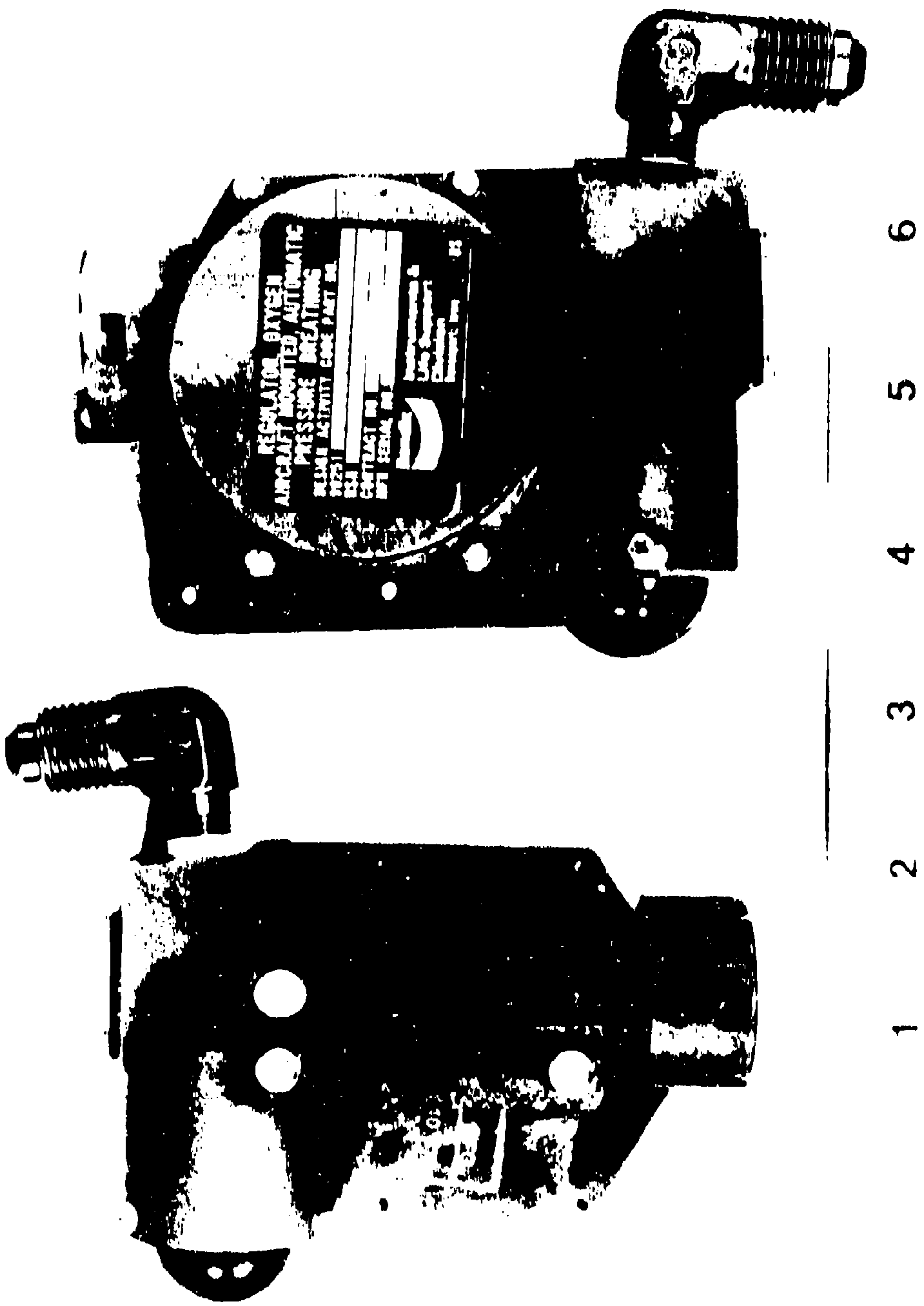


Figure 11 – OEAS Breathing Regulator

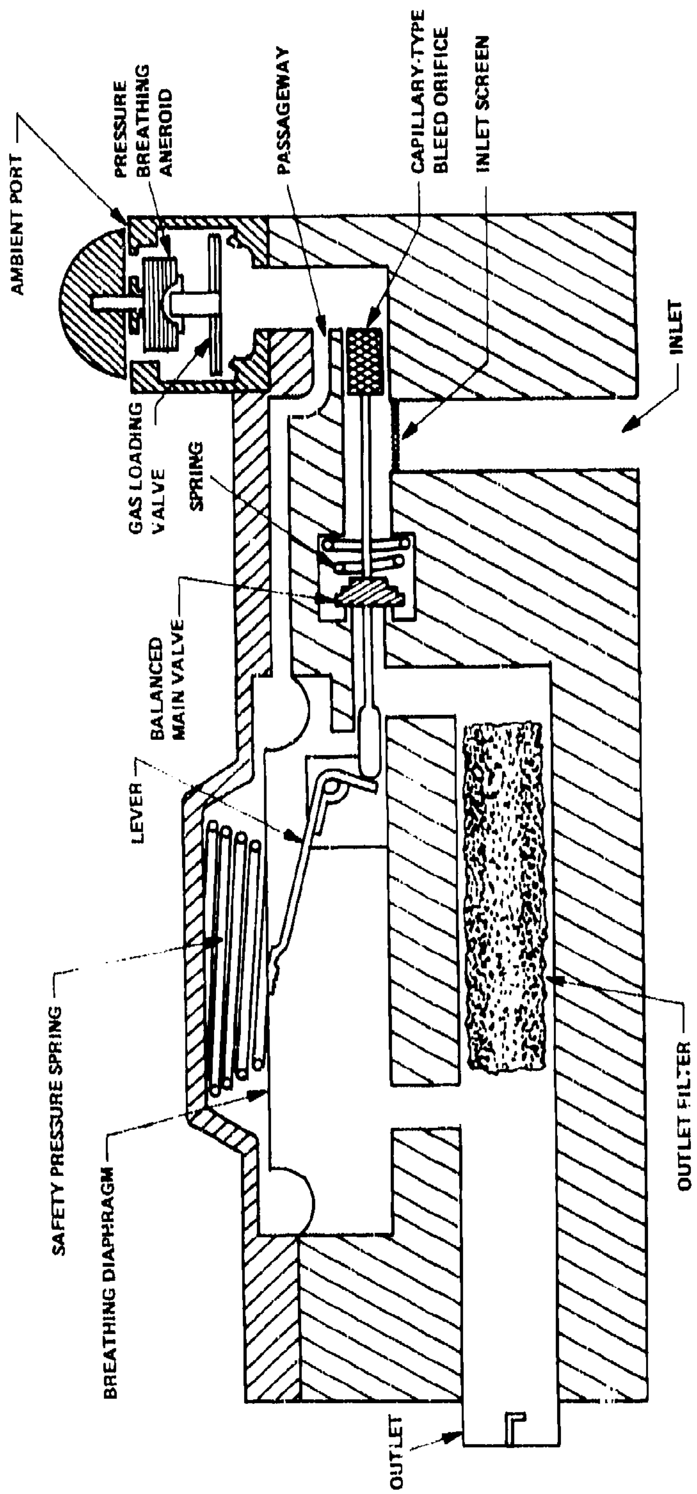


Figure 12 — Breathing Regulator Schematic

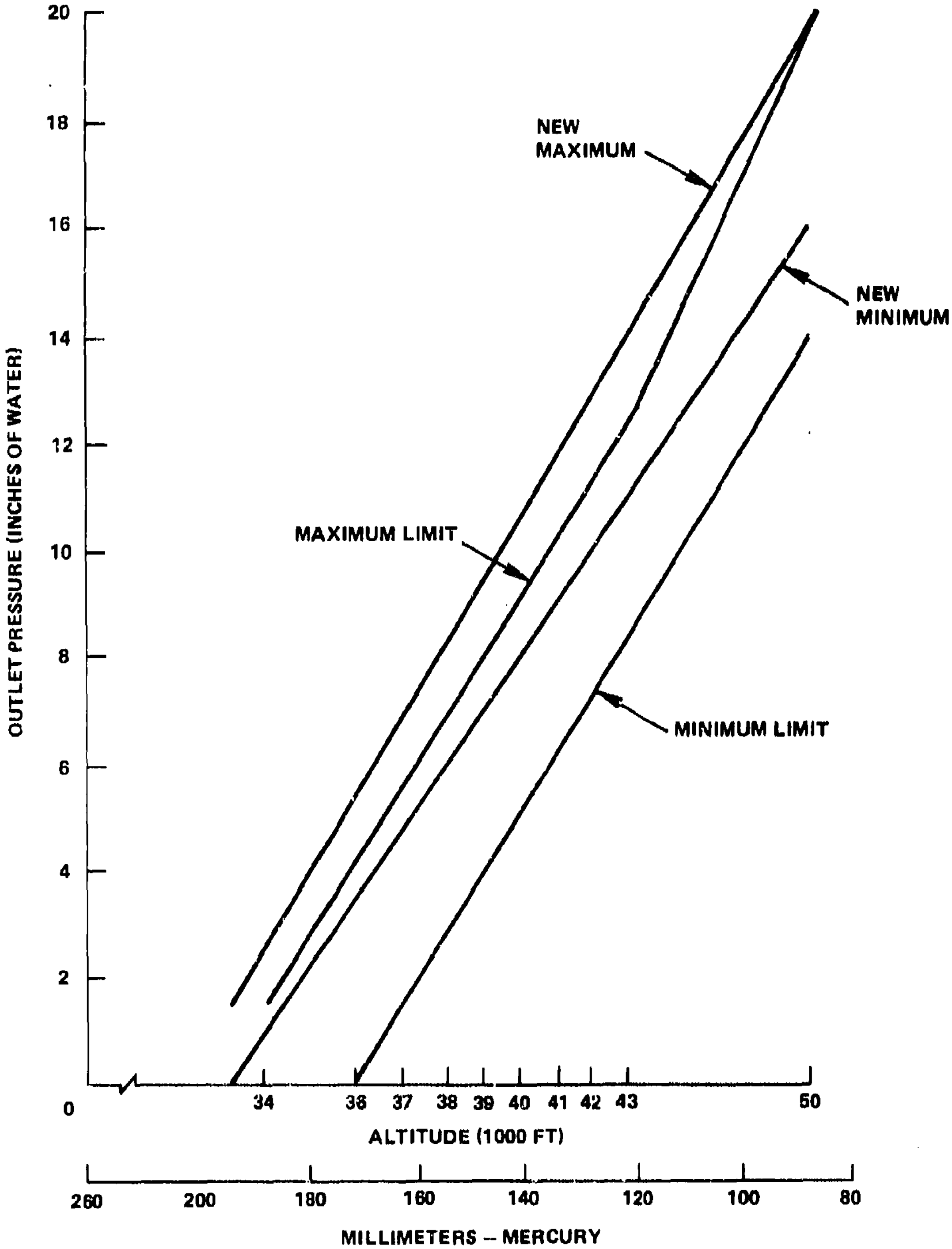


Figure 13 – Breathing Regulator Outlet Pressure Limits

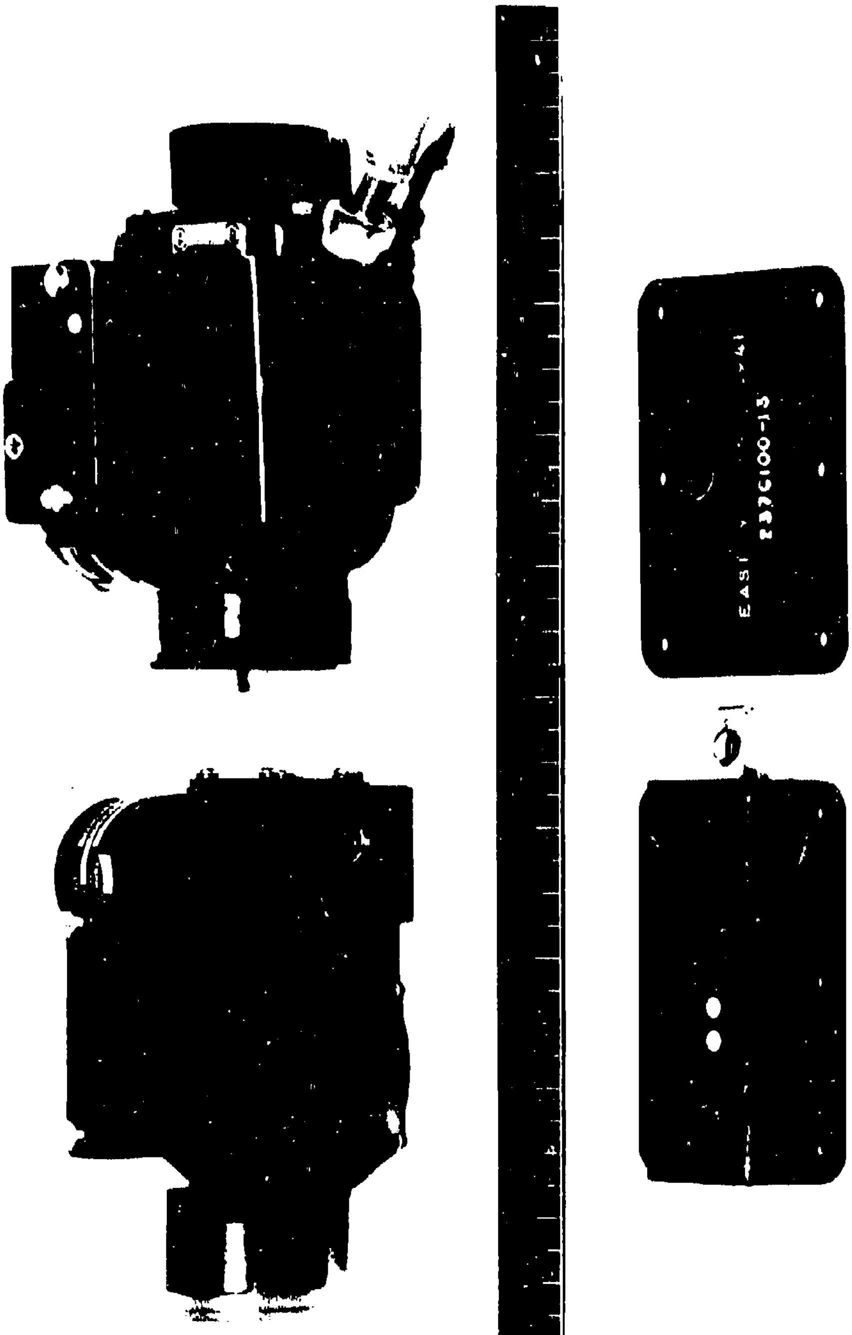


Figure 14 – OEAS Breathing Regulator and AV-8A Diluter Demand Regulator

OEAS PERFORMANCE MONITOR

The OEAS Performance Monitor, P/N 3270015-0301, was manufactured both by the Bendix Corporation and by Beckman Instruments, Inc. The monitor (Figures 15 and 16) has dimensions of approximately 3 inches by 3 inches by 5 inches and weighs one pound. Designed for airframe mounting within the aircraft cabin, the monitor continually receives a small sample of the oxygen enriched air being delivered to the aircrewman from the oxygen concentrator, and activates a warning light when the partial pressure of oxygen falls to 220 mm Hg. Figure 17 shows the warning light activation point at altitude. Under normal operation, the oxygen concentration delivered by the OEAS will be above this point.

Referring to the system schematic of Figure 18, the sample gas passes through a flow control orifice (limited to 1.0 lpm @ 25 psig) before passing across the oxygen sensing element and venting to the cabin. The compensating aneroid/valve mechanism is employed to maintain a constant absolute pressure equivalent to 28,000 feet in the sensor cavity to prevent a false warning signal in the event of the loss of cabin pressurization above 28,000. (The warning signal would be activated at approximately 30,500 feet even with 100% oxygen). A built in test, press-to-vent button is also incorporated to test the monitor during flight. By depressing this button, the inlet supply gas is directed away from the sensing element and, through a venturi effect, ambient (cabin) air is drawn through the vent port and across the sensor, activating the warning light.

The sensing element employed (Figure 19) is a polarographic type, which contains a gold cathode and silver anode immersed in a gel electrolyte sealed permanently in place with a Teflon membrane which is permeable to oxygen. A polarizing voltage applied between these two electrodes results in a current flow which becomes directly proportional to the oxygen partial pressure to which the sensor is exposed.

The electronic module consists of a power supply, amplifiers, a potentiometer to permit gain adjustment during routine calibration and after sensor replacement, and a small connector containing aircraft power (28W @ 28VDC), alarm output signal and calibration measurement terminals.

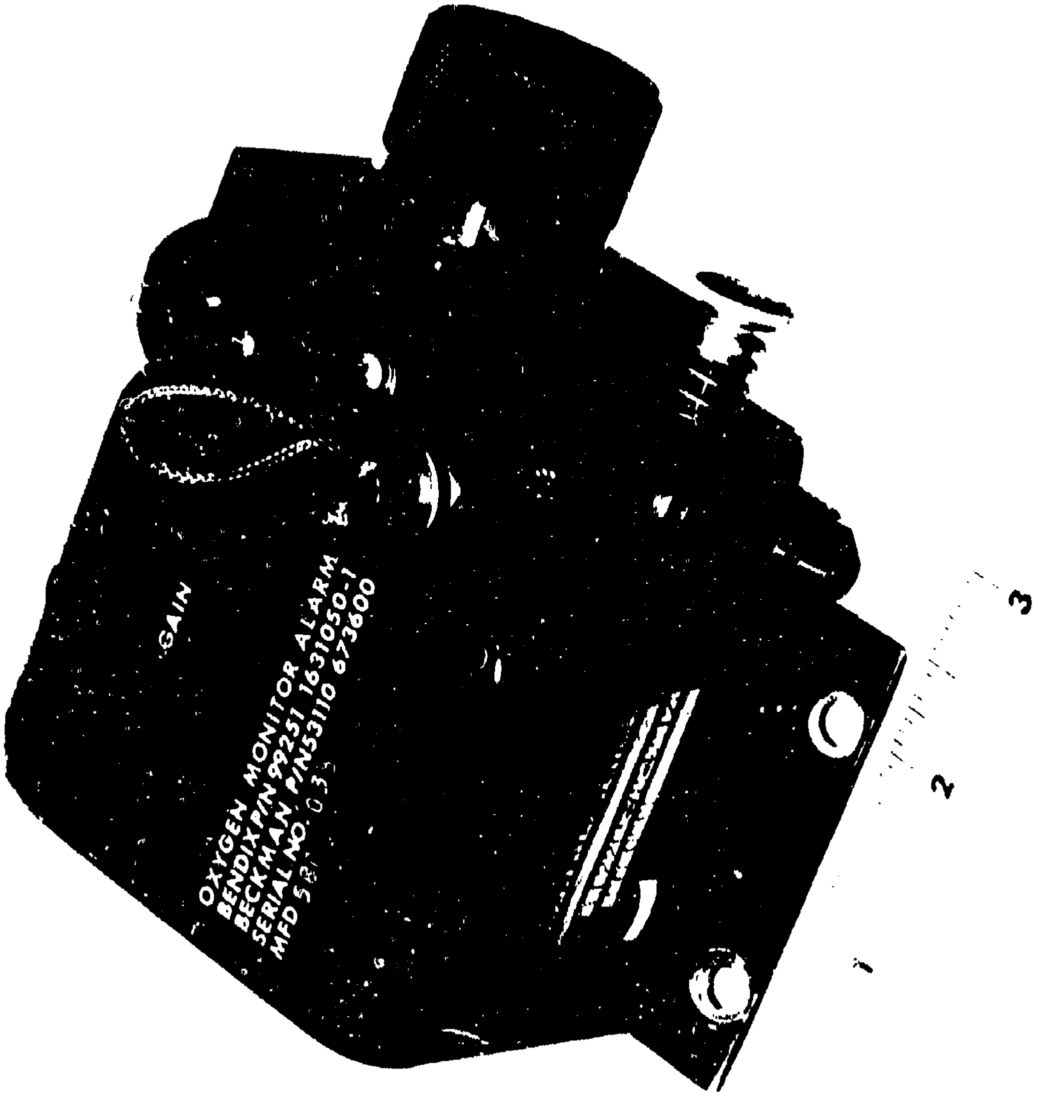


Figure 15 — OEAS Performance Monitor

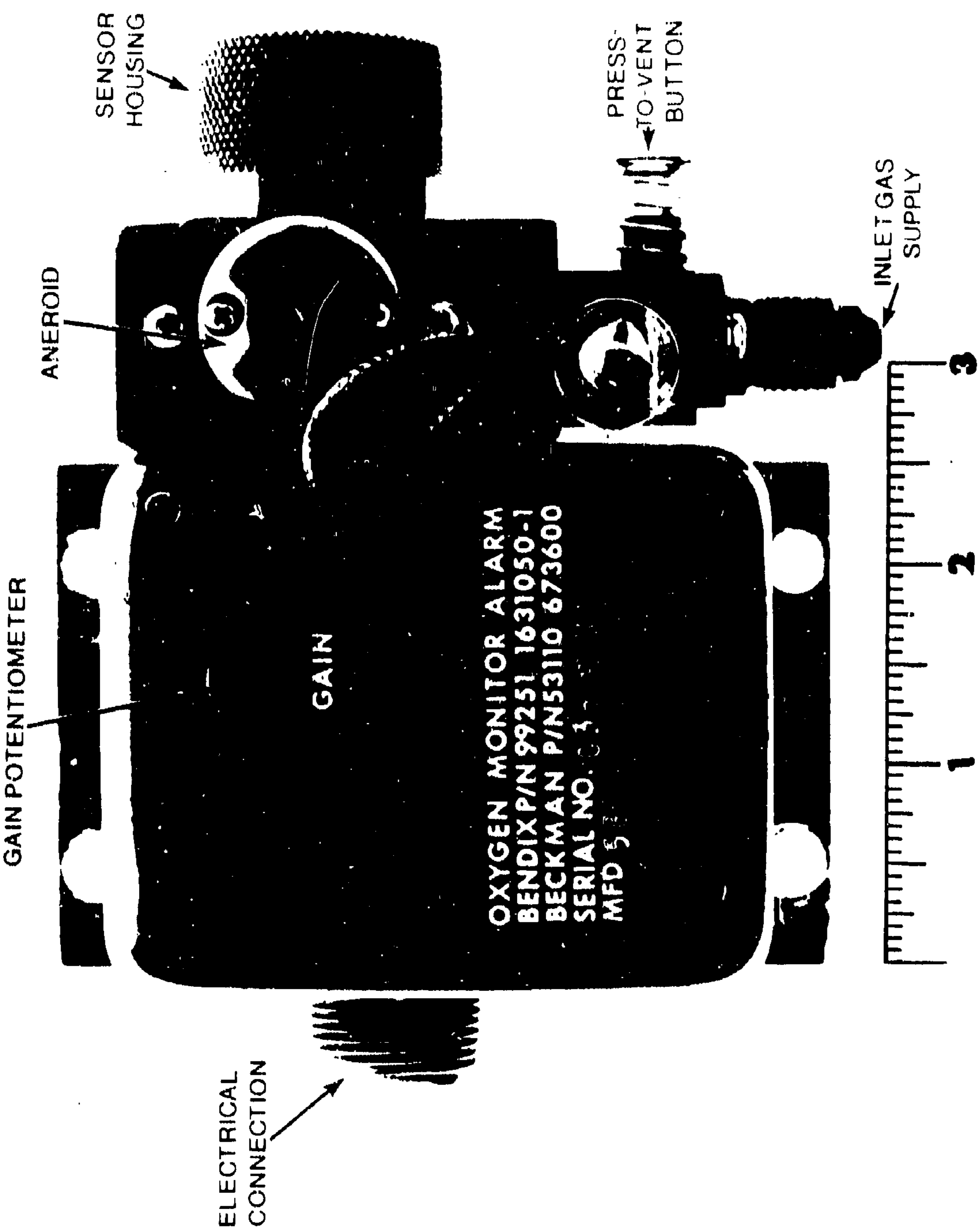


Figure 16 – OEAS Performance Monitor Main Components

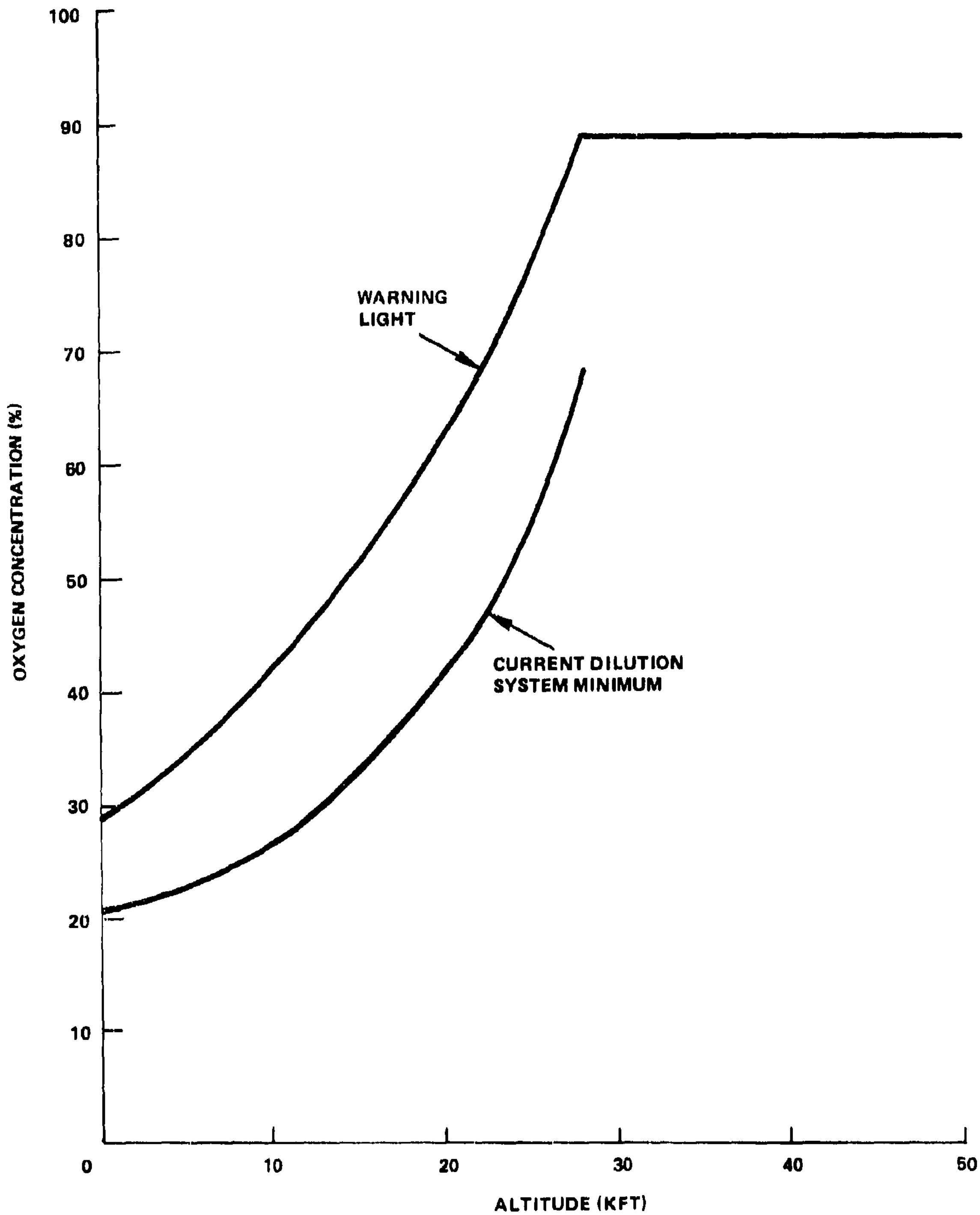


Figure 17 – Monitor Warning Activation Point

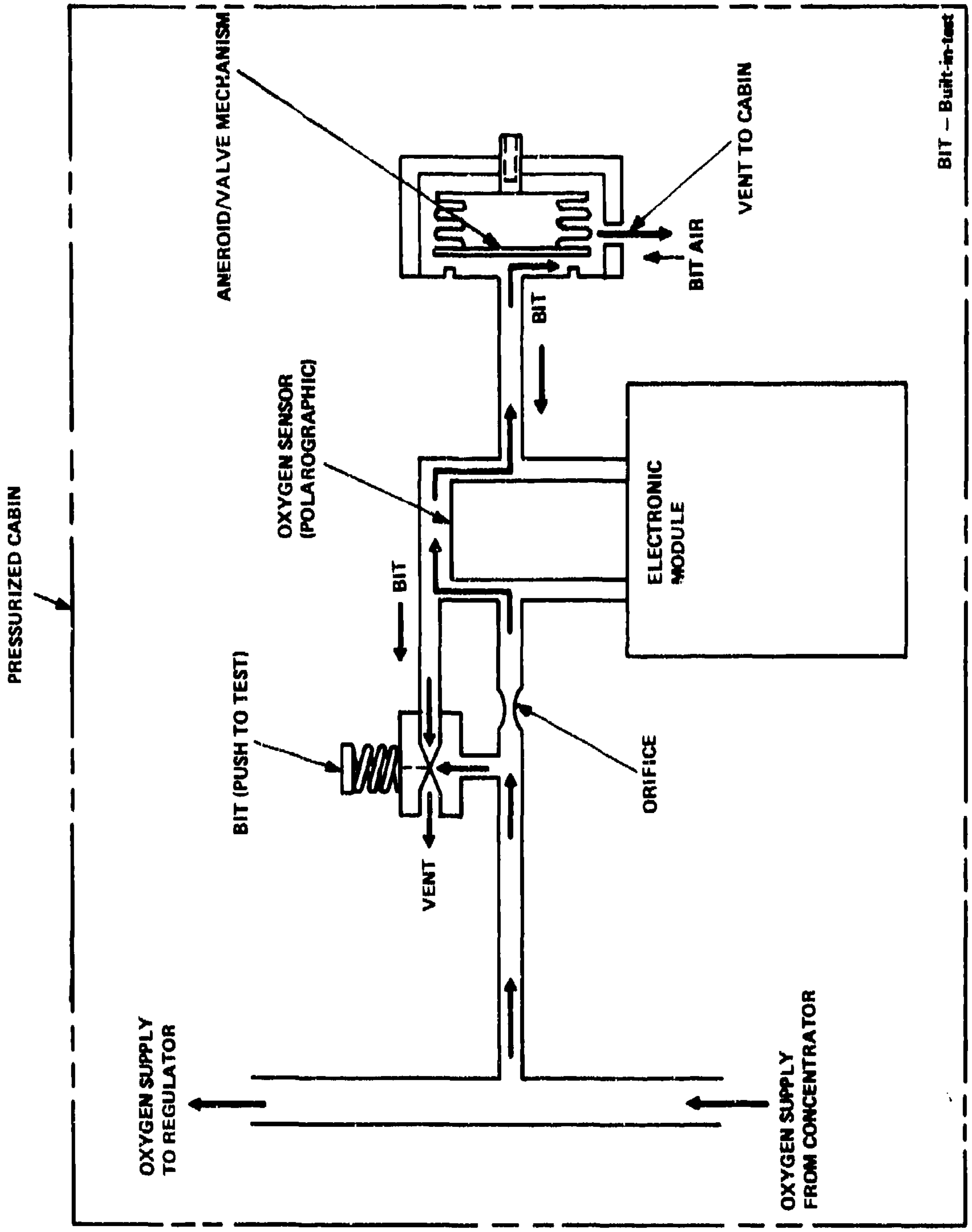


Figure 18 – Performance Monitor Schematic

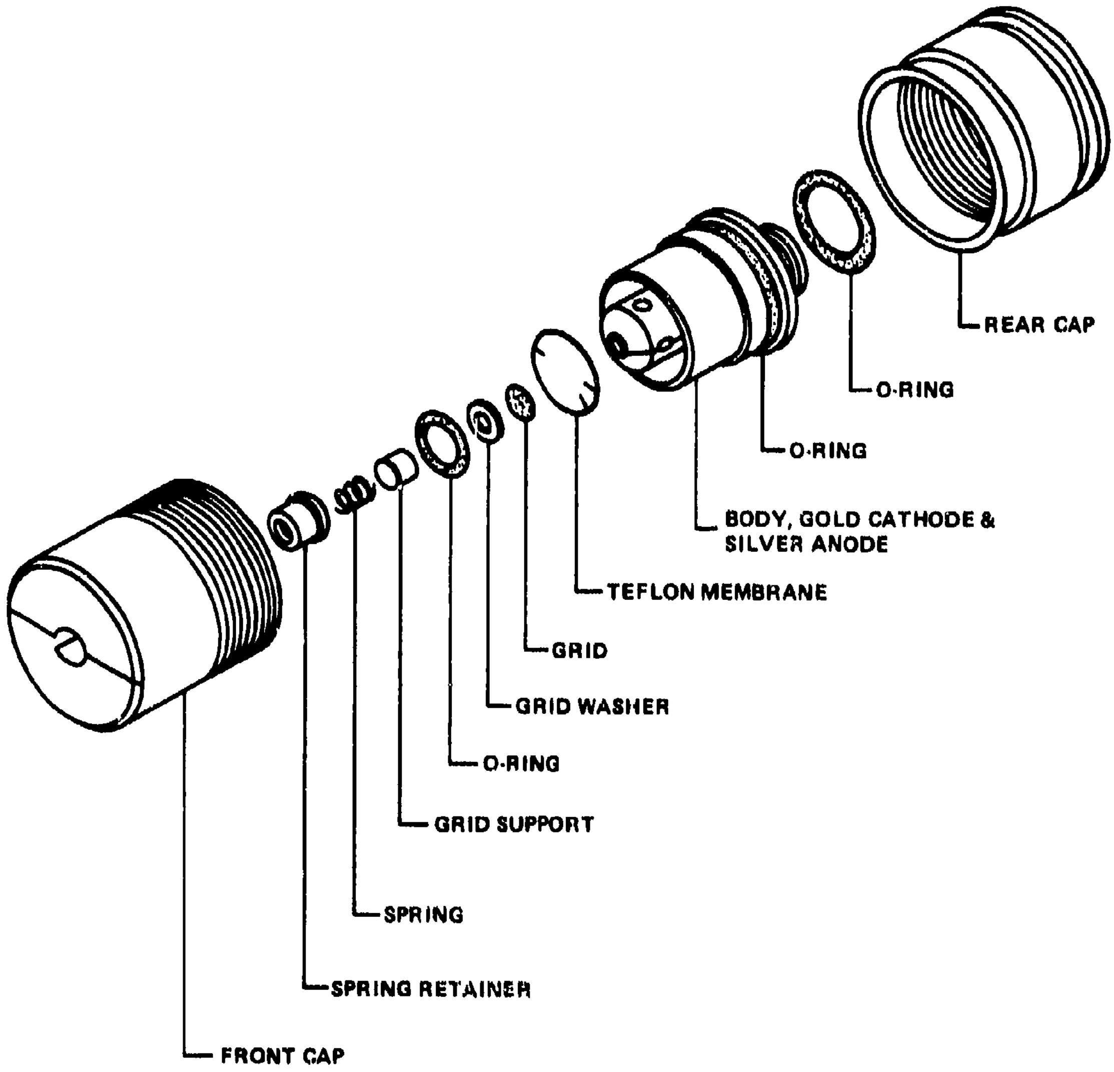


Figure 19 – Polarographic Oxygen Sensor

AIRCRAFT INSTALLATION/PERSONNEL EQUIPMENT

The AV-8A Harrier has been modified for OEAS incorporation by the McDonnell Aircraft Company, McDonnell Douglas Corporation, St. Louis, Missouri, under NAVAIRSYSCOM contract N00019-78-G-0052. An installation overview is presented in Figure 20, while a schematic of airframe modification upstream of the concentrator is presented in Figure 21.

Bleed air taken from the 8th stage of the Pegasus engine is passed through an air-to-air heat exchanger for reduction in typically high bleed air temperatures which are undesirable both to the molecular sieve system and for use as a breathing gas. This air is then passed through a pressure regulator, limiting the input pressure to the concentrator to a maximum of 28 psig. This regulator is incorporated as a means of limiting air consumption (which increases with pressure) and therefore inlet air temperature (due to flowrate reduction through the heat exchanger). Supplying bleed air at 250 psig to the concentrator will result in a bed supply pressure of approximately 67 psig and flowrate projected to a result in excessive (above 250°F) inlet air temperature. Temperature switches are incorporated to provide a warning signal in the event this temperature exceeds 250°F. The OEAS concentrator effluent gas passes through the existing 5/16 supply line to the cabin.

Upon arrival in the cockpit, the breathing gas first enters a 100 cubic inch plenum, providing reserve gas for periods when excessive breathing rates are required and some heat sink capability for periods when supply gas temperatures may be excessive. A sample line tees into the supply line downstream of the plenum to feed the Performance Monitor, which is airframe mounted.

In lieu of passing through the normal breathing gas circuit (through the Restraint and Life Support Assembly (RALSA) and to a chest mounted regulator), the gas passes through a modified configuration. The new breathing gas circuit (Figure 22) has been incorporated to improve low bleed air pressure performance during sea level idle operation, where essentially all regulator supply pressure is lost. Raising the setting of either the bleed air regulator or concentrator pressure reducer would not improve performance at low bleed pressure. The modified design utilizes a low pressure drop line hose routing in the pilot's personal gear. The chest mounted regulator is relocated to a right hand Environmental Control System (ECS) panel and is now airframe mounted. The RALSA is modified to eliminate its manifold and flow through feature and tees into the aircraft supply line.

The modified RALSA (Figure 23) incorporates an automatic, absolute pressure, 100% oxygen regulator (3.5 ounces; 3 in x 2 in x 1.5 in). Bottled emergency gas at 1800 psig is reduced to approximately 60 psig for regulator input, which provides a breathing pressure of 2 to 20 inches of water, depending on altitude. The outlet hose for the RALSA is routed behind the seat cushion to the right side and to the CRU-60/P chest mounted connector. This configuration (Figure 24), hereafter referred to as the Personnel Hose Assembly, also incorporates a 24 inch length, 1 inch diameter hose from the OEAS (primary) breathing regulator to the CRU-60/P.

On ejection, this hose disconnects at the CRU-60/P and, along with the OEAS regulator, remains with the aircraft. Spring stiffening was necessary to the CRU-60/P at this point to prevent the entrance of water during underwater breathing. Due to the location of the CRU-60/P connector on the right side of the MA-2 torso harness, the AV-8A system utilizes a soft (MBU-14/P) hose from the CRU-60/P to the A-13A mask to provide the ability of a head turn to the far left. Additional breathing circuit modifications to minimize pressure drop include elimination of the behind the seat crossover which shortens the line by two feet and increasing the diameter of this hard line from 5/16 O.D. to 3/8 O.D.

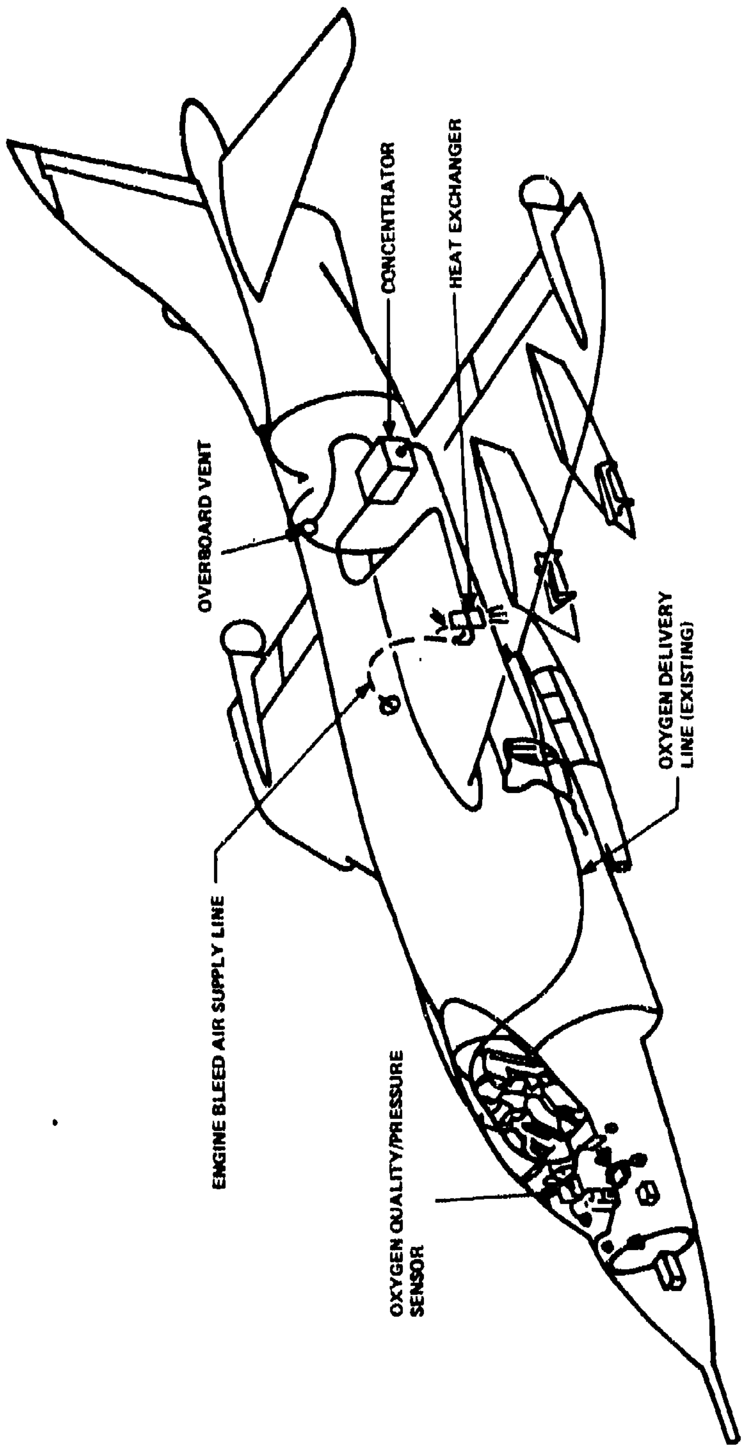


Figure 20 — AV-8A OEAS Installation Overview

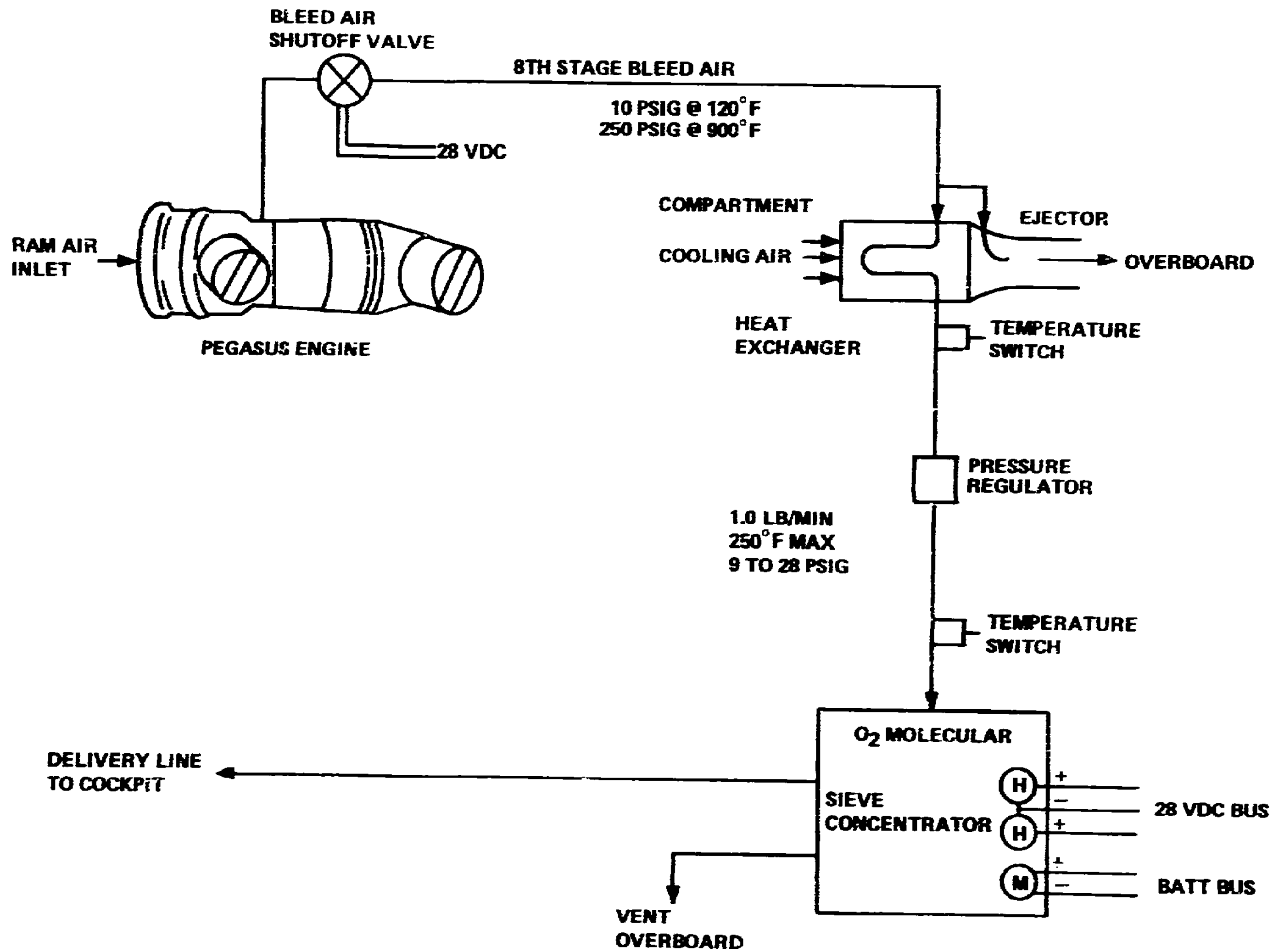


Figure 21 – AV-3A Concentrator Installation Schematic

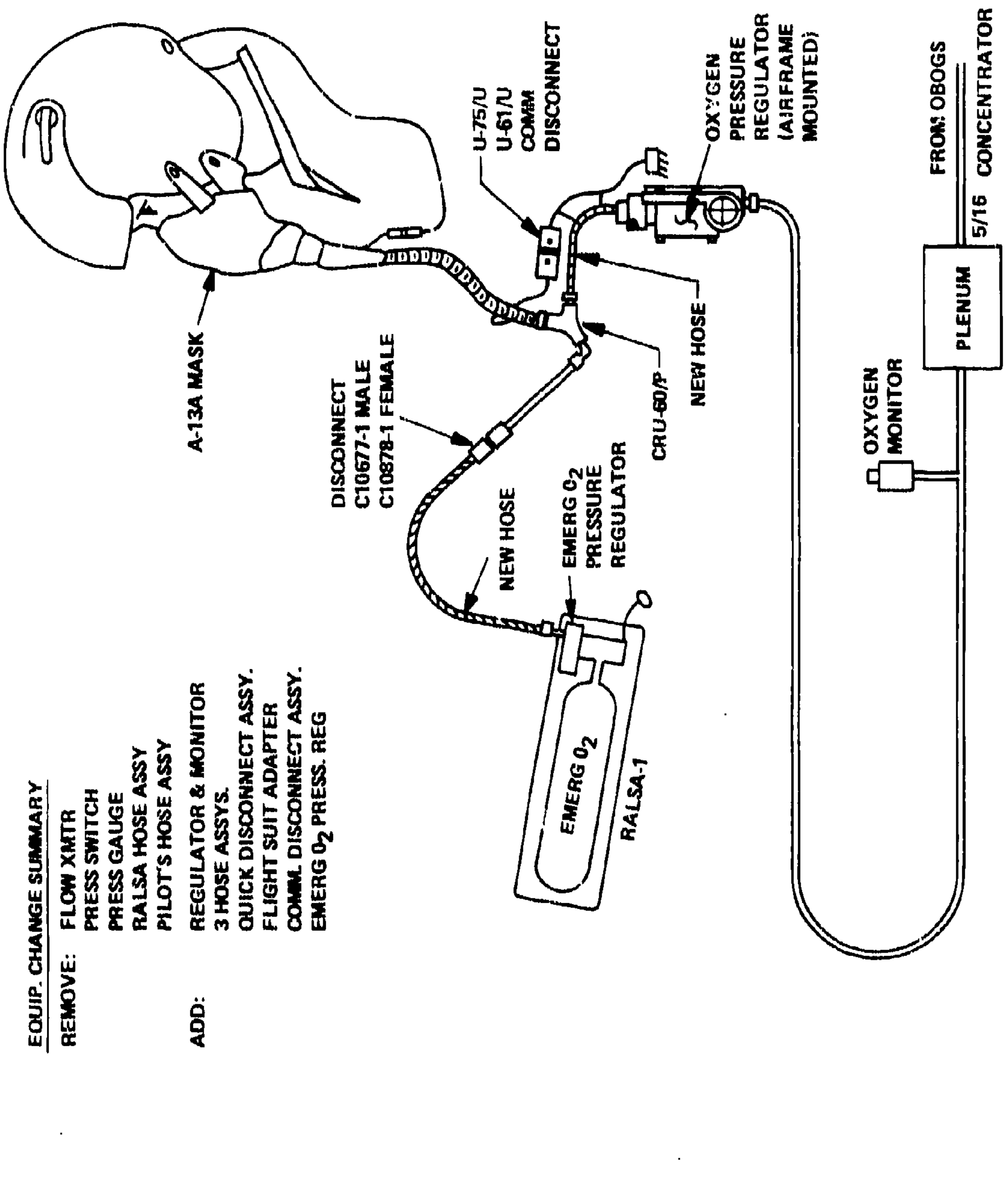


Figure 22 — AV-8A OEAS Concept Installation Schematic

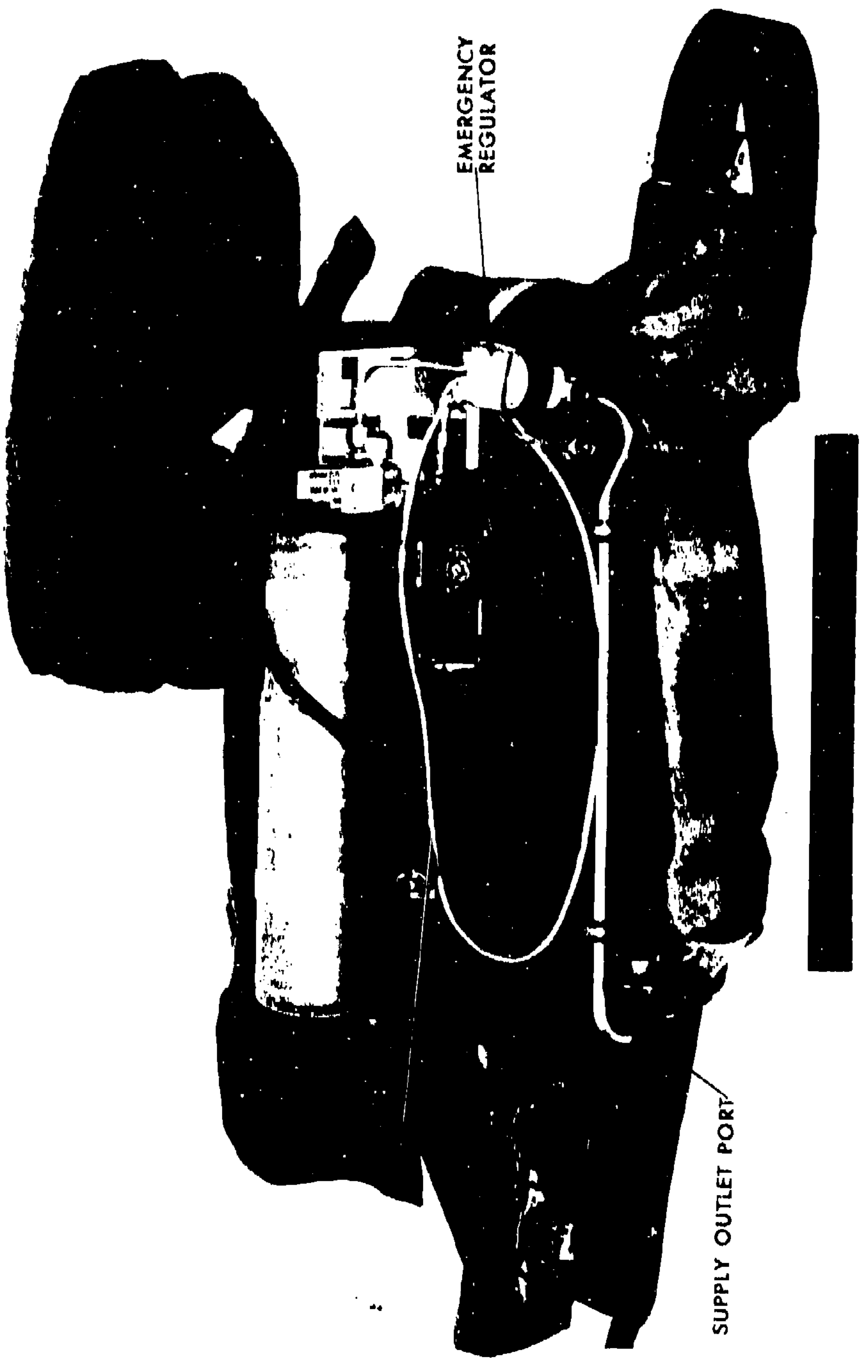


Figure 23 — Modified Restraint and Life Support Assembly (RALSA)

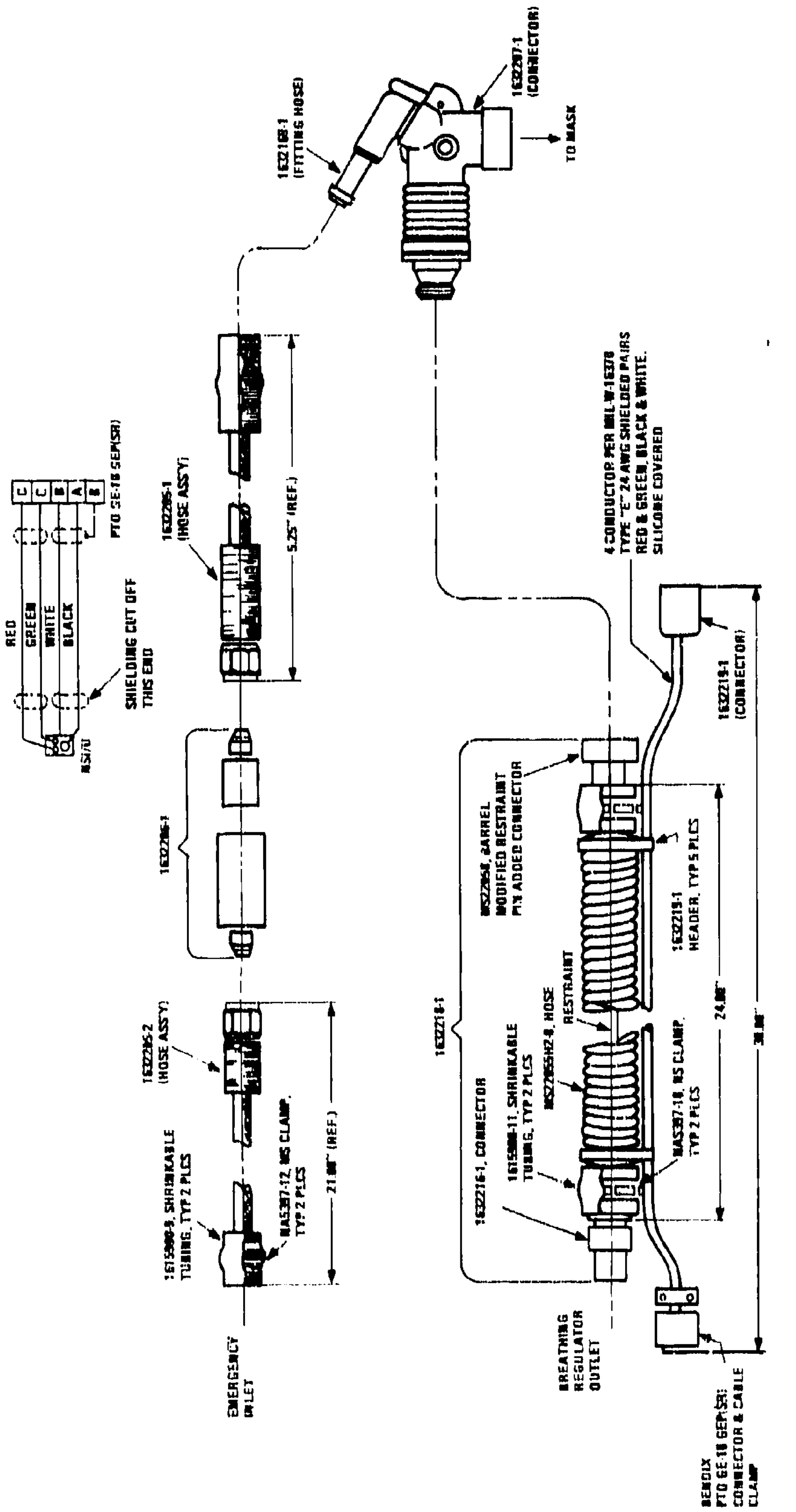


Figure 24 — Personnel Hose Assembly

TEST METHODS AND EQUIPMENT

Oxygen Concentrator

The ability of the oxygen concentrator to provide an adequate breathing gas quality was of prime concern in the program, and was determined as a function of inlet pressure, outlet flowrate and altitude (nitrogen exhaust pressure). Concentrator performance was also evaluated with variation in ambient and inlet air temperature, testing not only to conditions anticipated on the AV-8A, but also to design extremes.

The test apparatus employed in this evaluation is presented schematically in Figure 25 and pictorially in Figure 26. Referring to Figure 25, house air (95 psig, 70 ±10°F) was first passed through a dryer and filter assembly for removal of oil, water vapor and particulate matter. This conditioned air then passed through a diaphragm regulator for variation of inlet pressure, and through an air heater/chiller for variation of inlet air temperature, which along with pressure and flowrate, was monitored continually through each test. Nitrogen exhaust temperature, inlet air downstream of the internal heaters, and surface temperatures of the motor and electronics module were also monitored throughout each test. The concentrator was placed on a mounting tray, identical to that in the lox bay of the AV-8A, to obtain additional information on the ability of the electronics module to dissipate generated heat. Three DC power supplies were employed; one for each heater and one for the motor, solenoid and control electronics.

Enriched air flowrate was controlled via a needle valve after entering a pressure regulator for flow stabilization. For those conditions where a more steady outlet flow became desirable, a 2100 cubic inch surge tank (with gate valve) was used in place of the regulator. Flow was measured with a float type meter, exhausting to normal temperature and pressure (14.7 psia and 70°F). A sample of this gas (400 cc/min) was taken and processed by an oxygen analyzer. These results, which showed a concentration of oxygen (±1 percent error), were also monitored continually during each test and recorded manually. Gas samples were also drawn at several points and analyzed through use of a chromatograph for a more detailed composition breakdown.

MIL-STD-810C (17) was utilized to establish environmental stress testing guidelines, and where applicable, test levels for full qualification conducted. Basic testing procedure involved measurement of oxygen concentration, outlet pressure, power consumption, etc. and noting any deviation, along with any structural deformation during, as applicable, or after exposure to any environmental stress.

A detailed description of each test is described in the sections that follow.

Breathing Regulator

The ability of the breathing regulator to provide a breathing gas of adequate quality (outlet pressure) and quantity was of prime concern in the program. Testing was accomplished under the guidelines of MIL-R-81553 (AS) of the regulator, modifications were made, as applicable, to the individual tests. Safety and pressure breathing outlet pressures were determined as a function of inlet pressure, outlet flow and high and low ambient temperature. Inlet pressures were varied throughout the program, testing not only to those anticipated on the AV-8A, but to values below minimum which may be encountered in future aircraft installations and to those maximums available with standard LOX systems. Environmental stress testing was also accomplished with measurement of outlet pressure during, as applicable, or after any environmental stress with any deviation or structural deformation noted. All testing was accomplished on two regulators, S/N 808010E and 810011E, both delivered, and subsequently modified, under contract 78-C-0128.

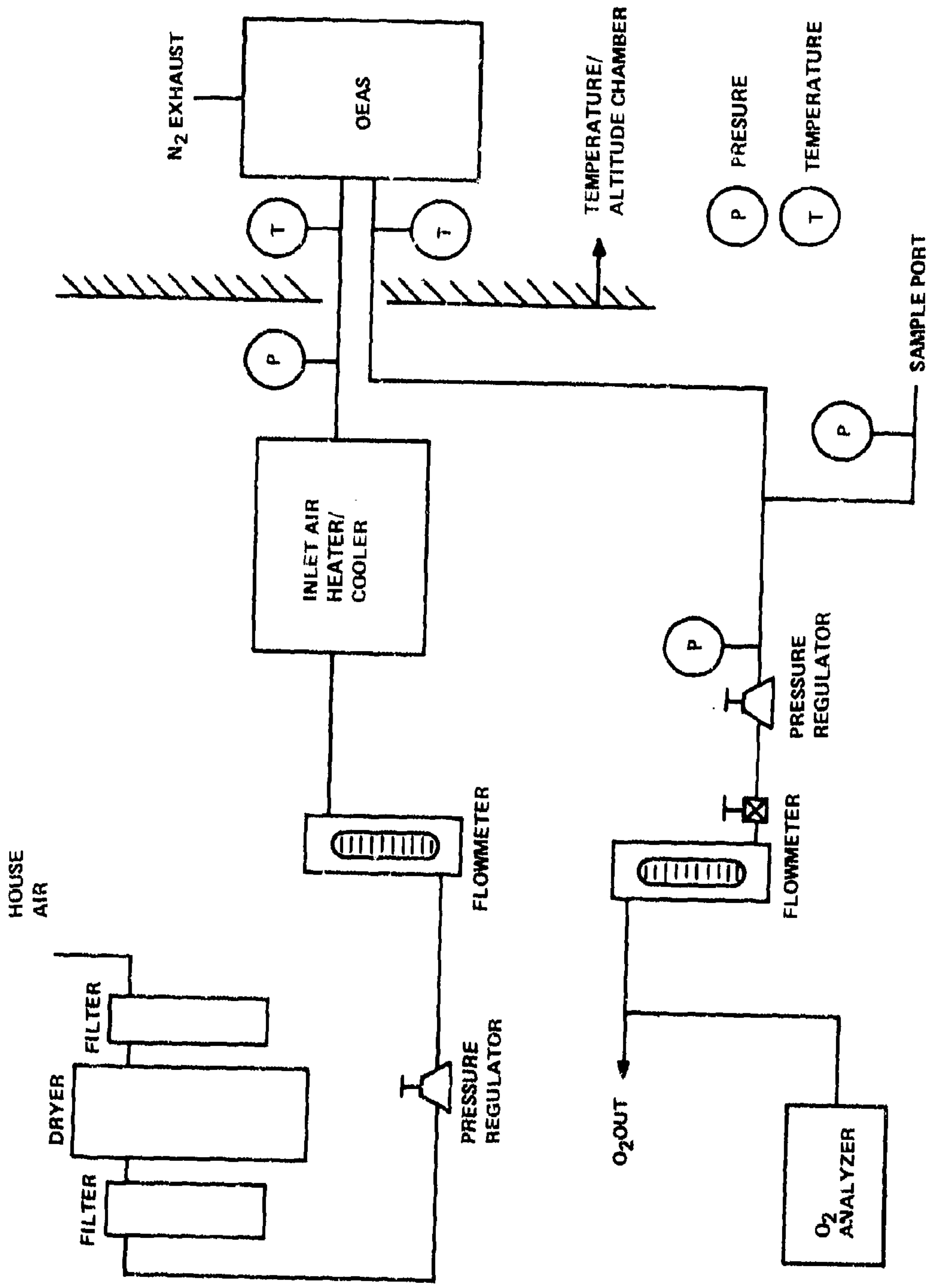


Figure 25 – Oxygen Concentrator Test Set Up Schematic

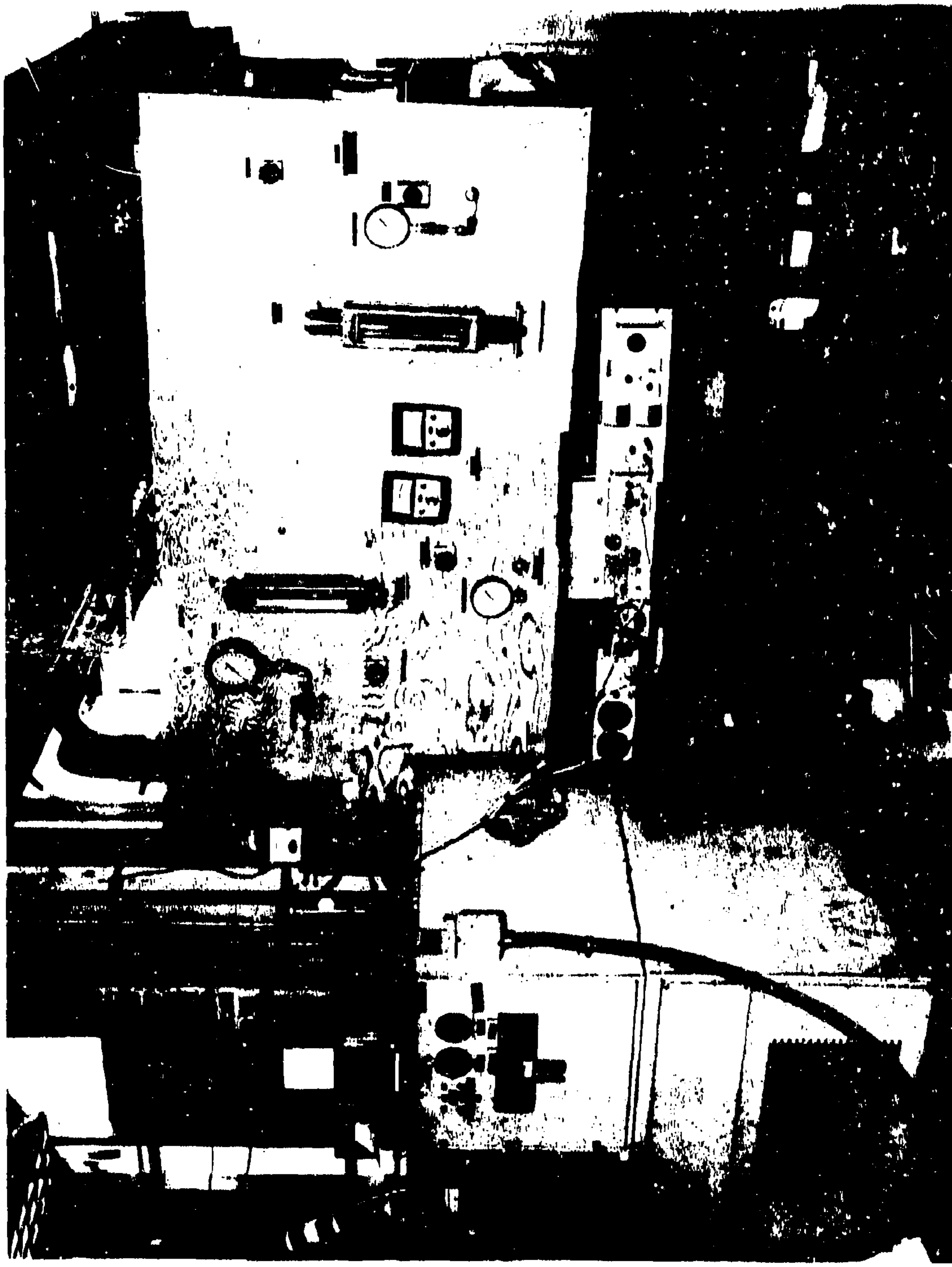


Figure 26 – Oxygen Concentrator Test Equipment

All outlet pressure tests at altitude (30,000 feet or above) were accomplished utilizing National Instruments Test Stand, P/N OTS-565, modified for variation of ambient temperature. During these and all other outlet pressure tests specified herein, the outlet of the regulator remained in the vertical position (as installed in the aircraft) with pressures measured at the outlet of the CRU-60/P connector, i.e., the personnel hose assembly itself was used in lieu of a piezometer assembly.

Specific test procedures, with any deviation to those presented in MIL-R-81553, are presented in the sections that follow.

Performance Monitor

The ability of the performance monitor to provide a warning signal when required was of prime concern in the program. Testing involved conducting individual performance tests to verify normal operation, environmental stress testing in accordance with MIL-STD-810C, and electromagnetic interference in accordance with MIL-STD-461(A)(18). All testing was accomplished on two monitors, S/N 808009E and 808010E, both delivered under contract 78-C-0128.

The typical monitor test set up is presented in the schematic of Figure 27. Air and oxygen were mixed to provide a gas of varying oxygen concentration and inlet pressure to the monitor. Output signal in millivolts was constantly monitored throughout each operational test which, after conversion to a corresponding oxygen concentration, was verification checked through use of an oxygen analyzer. Basic test procedure involved conducting the individual tests prior to environmental stressing and noting any deviation or structural deformation during, as applicable, or after each stress test, with particular attention given to calibration points and warning activation capabilities.

A detailed description of each test is presented in the sections that follow.

TEST RESULTS AND DISCUSSION

OEAS OXYGEN CONCENTRATOR

Operation at Sea Level

OEAS Oxygen Concentrator inlet air consumption for all operating inlet air pressures at sea level is presented in Figure 28. With inlet air consumption always increasing with inlet (bleed) air pressure, the rate of increase from approximately 25 psig to 250 psig changes due to the effects of the concentrator's (internal) pressure reducer. The limits for maximum and minimum reducer outlet (bed inlet) pressures are presented in Figure 29 and Table 1. Concentrator bed inlet pressure, and therefore air consumption and outlet pressure can vary from unit to unit. Air consumption at 25 psig inlet air pressure or below, will not show any variance, as 25 psig is the minimum activation or "kick in" pressure for any concentrator.

The typical inlet air waveform (flow vs. time) is presented in Figure 30. Time zero can be considered the beginning of air inlet to one bed, and also to evacuation of the second bed. Maximum inlet flowrate occurs approximately 0.8 seconds later (with all inlet pressures). Flowrate then decreases at a fairly uniform rate and again drops to zero at 5 seconds. A bed purge/nitrogen enriched exhaust therefore occurs every 5 seconds. With absorption/desorption of both beds every 10 seconds, control valve speed is one revolution/10 seconds or 6 revolutions/minute. Inlet air consumption increases with pressure, with a higher peak reached at 0.8 seconds and corresponding increase in area under the waveform.

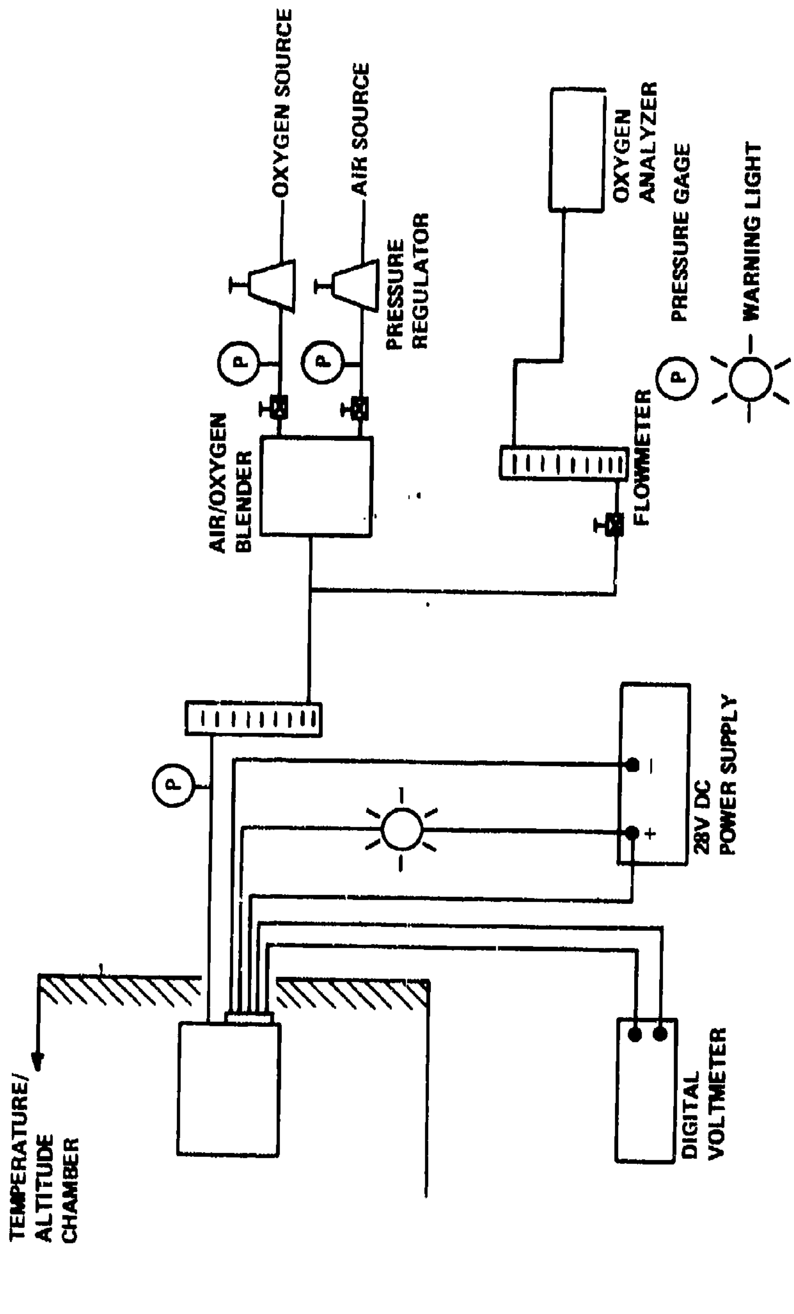


Figure 27 — Performance Monitor Test Setup Schematic

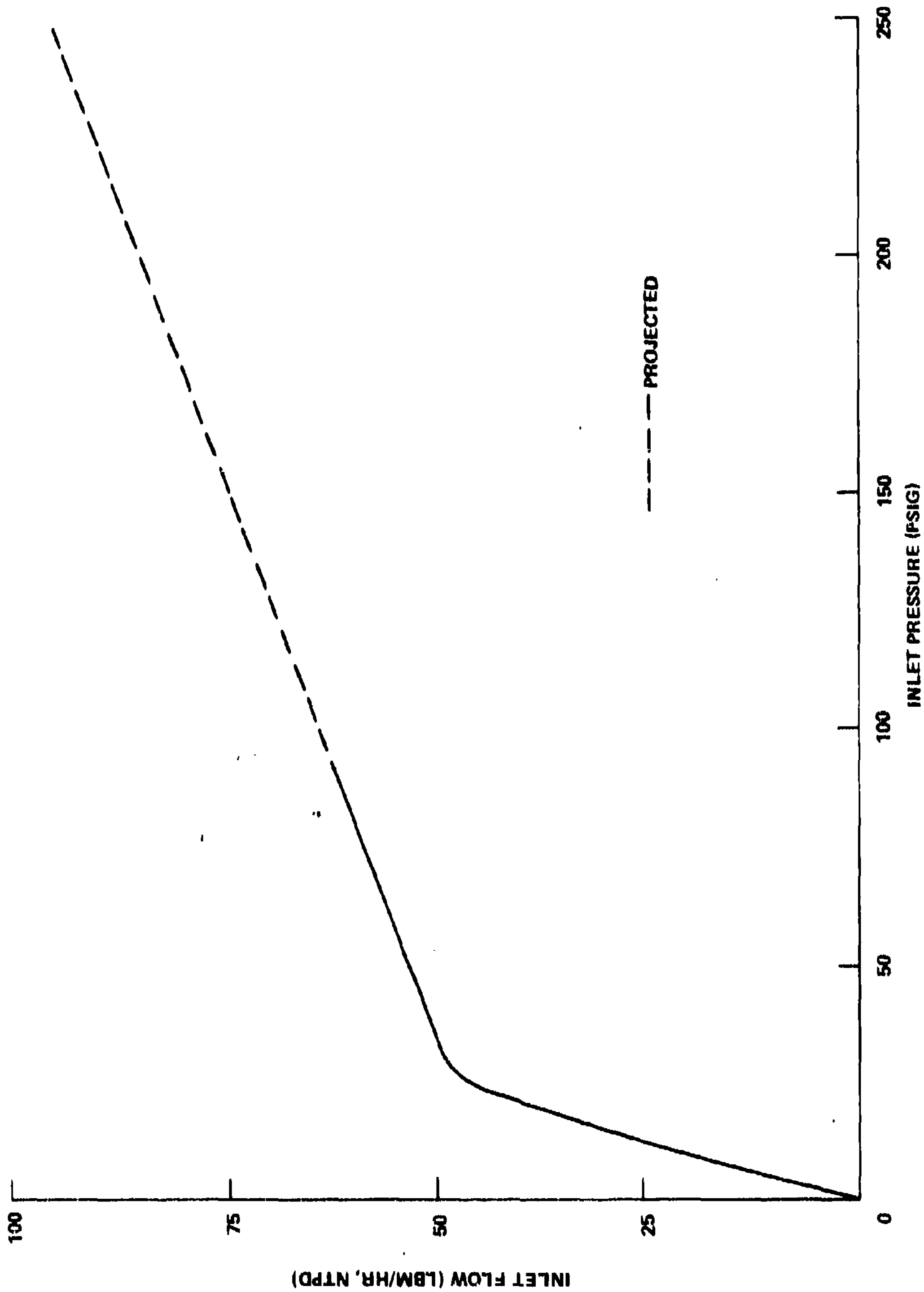


Figure 28 — OEAS Concentrator Inlet Flow Vs. Inlet Pressure at Sea Level

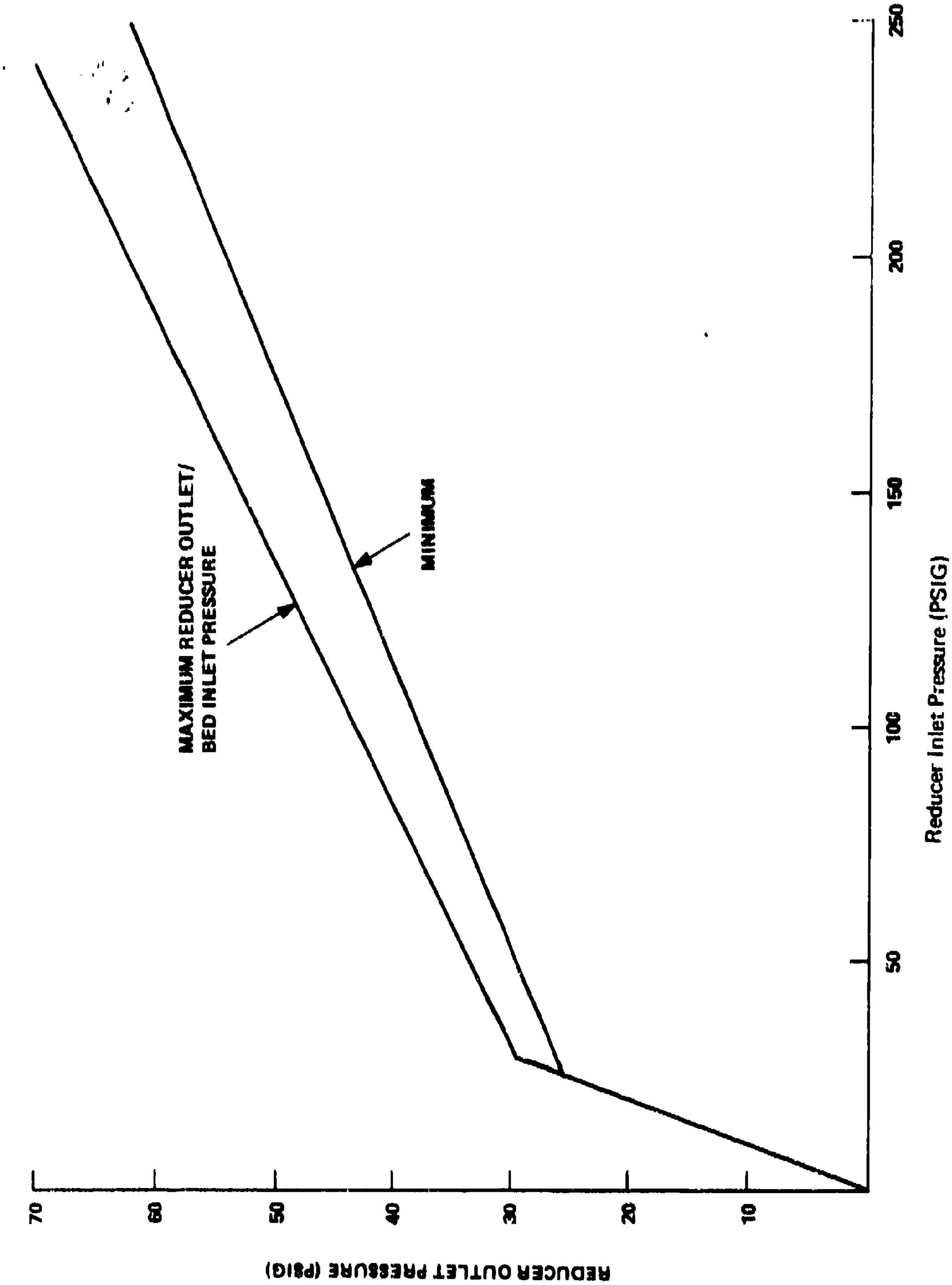


Figure 29 – Reducer Outlet Vs. Inlet Pressure

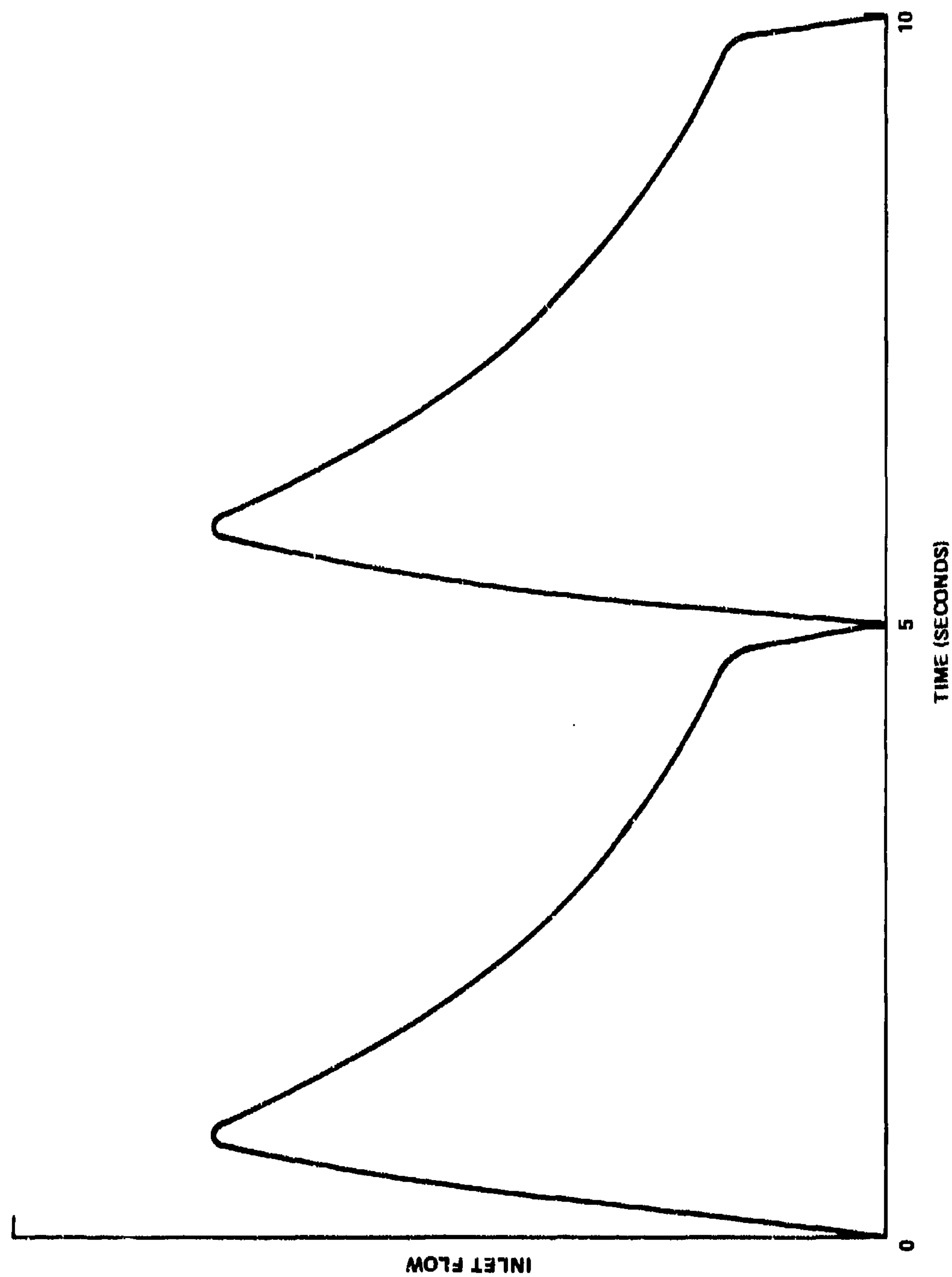


Figure 30 – Oxygen Concentrator Inlet Flow Vs. Time

Table 1

OEAS CONCENTRATOR REDUCER OUTLET PRESSURES

Reducer Inlet Pressure (Psig)	Reducer Outlet Pressure (Psig) Minimum	Maximum
25.0	25.0	25.0
29.5	26.0	29.5
35.0	27.0	30.5
45.0	28.5	32.5
60.0	31.0	35.5
90.0	36.0	41.0
150.0	46.0	53.0
200.0	54.0	62.0
250.0	62.0	72.0

Oxygen concentration at sea level was determined as a function of inlet air pressure and oxygen enriched gas outlet flow. Figure 31 depicts oxygen concentrations delivered as a function of outlet flow for various inlet pressures while those delivered as a function of inlet pressure as presented in Figure 32. The basis used in this evaluation was made through utilization of one man breathing gas flowrates as specified in MIL-D-19326 (11) and presented in Table 2, and the bleed air pressures anticipated from the 8th stage of the AV-8A's Pegasus engine (Table 3). The data used in the construction of these plots is presented in Appendix A. All oxygen outlet flowrates are referenced to normal temperature and pressure.

Oxygen concentrations measured increased with inlet air pressure, due to a greater mass flow and more oxygen available, and decreased with outlet flow, due to the rate at which air is drawn through the beds and reduction in time for concentration. Maximum oxygen concentrations (in excess of 94 percent) were measured with an outlet flow of 5 lpm with inlet pressures of 13.5 psig (AV-8A idle descent) or above. Concentrations delivered for a one man breathing flowrate were above 28.95 percent (220 mm Hg at sea level) with inlet pressures of 8 psig or above. In addition, breathing gas flows in excess of 70 lpm can be drawn prior to warning activation with an inlet of 28 psig, the maximum pressure deliverable on the AV-8A. Once again, the non-uniform rate of increase in oxygen concentration with inlet pressure is due to the pressure reducer (which limits bed inlet pressure). The maximum deliverable breathing gas flowrates for various inlet pressures is presented in Table 4. These are the flowrates which drop oxygen concentration enough to activate the warning light (tolerance 220 ±10 mm Hg).

The approximate pressure drops through the concentrator are presented in Figure 33 for various inlet air pressures. The inlet pressures shown are those supplied to the concentrator (air heater), while the outlet pressures shown for zero flowrate are essentially those supplied to the system beds. Outlet pressures for various flowrates were measured approximately 6 feet from the breathing gas delivery port (5/16 in. O.D. tubing utilized).

Although the argon concentrations resulting from a specific oxygen concentration can be estimated through a ratio of their concentrations in air, a means of oxygen/argon separation (and therefore direct measurement) was utilized by the Aero Materials Laboratory of ACSTD (4). The results, which show the argon concentrations in the breathing gas for all oxygen concentrations deliverable by the system (independent of inlet pressure and outlet flow) is presented in Figure 34.

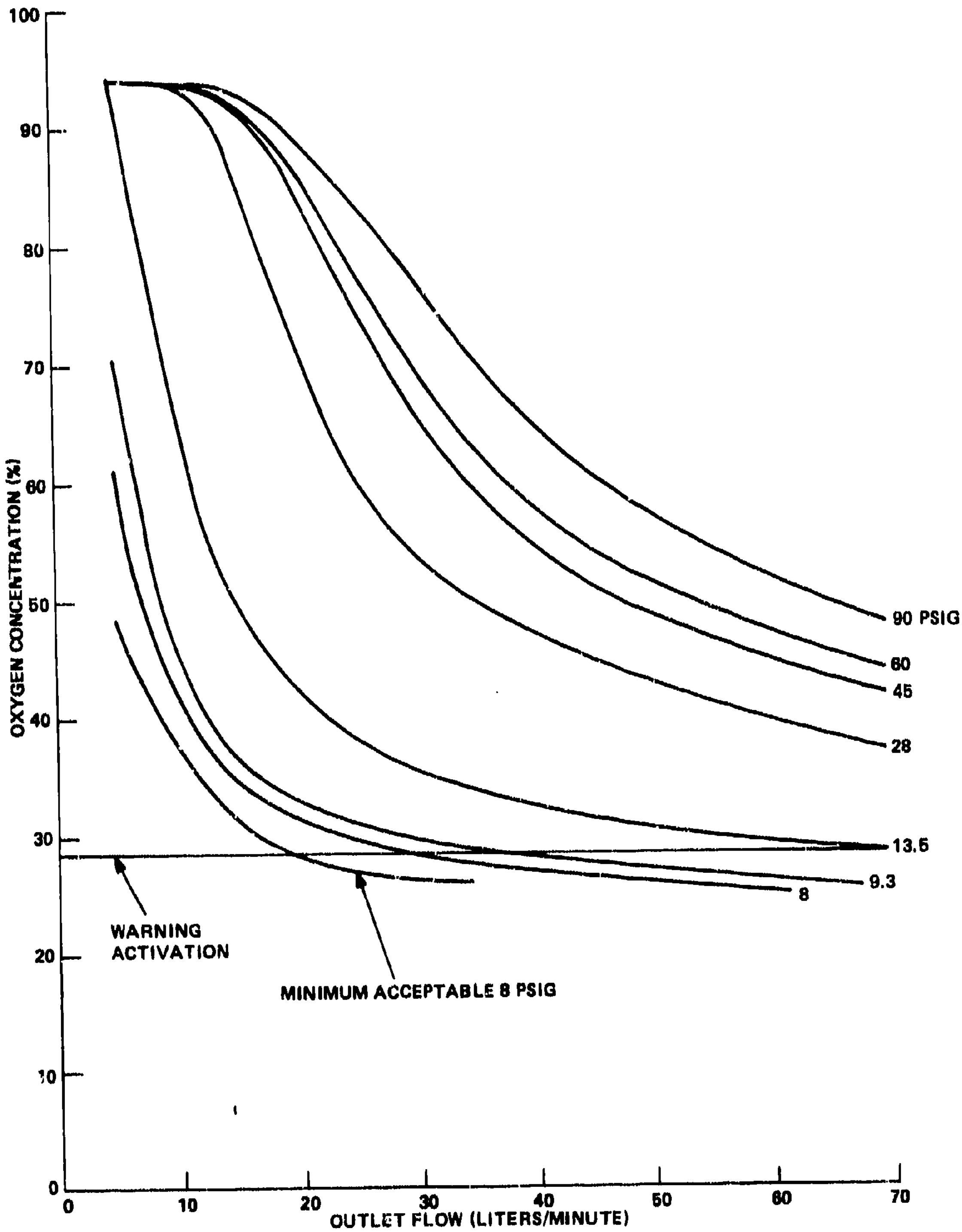


Figure 31 – Oxygen Concentration Vs. Outlet Flow for Various Inlet Pressures at Sea Level

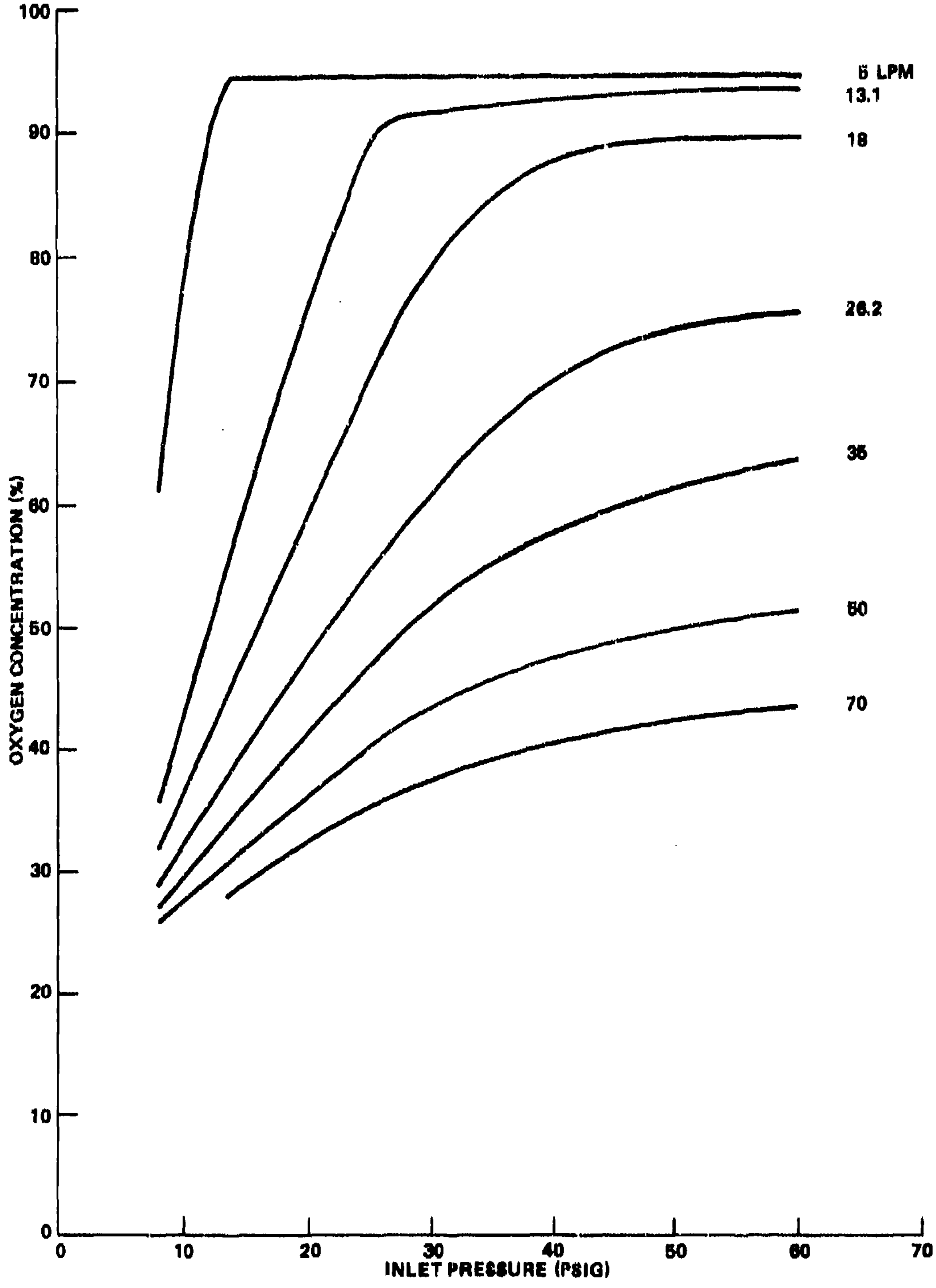


Figure 32 – Oxygen Concentration Vs. Inlet Pressure at Sea Level

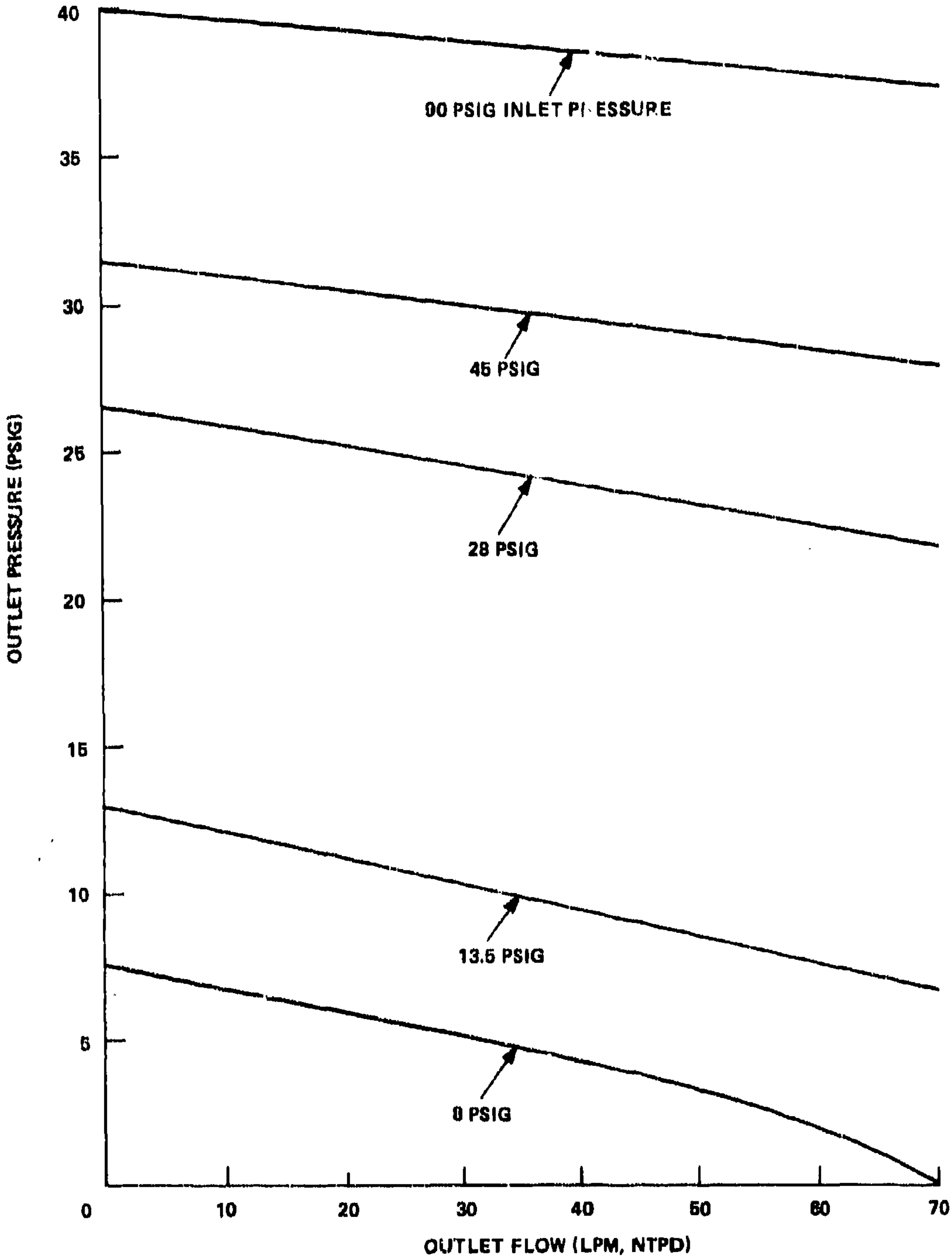


Figure 33 — Oxygen Concentrator Outlet Pressure Vs. Outlet Flow

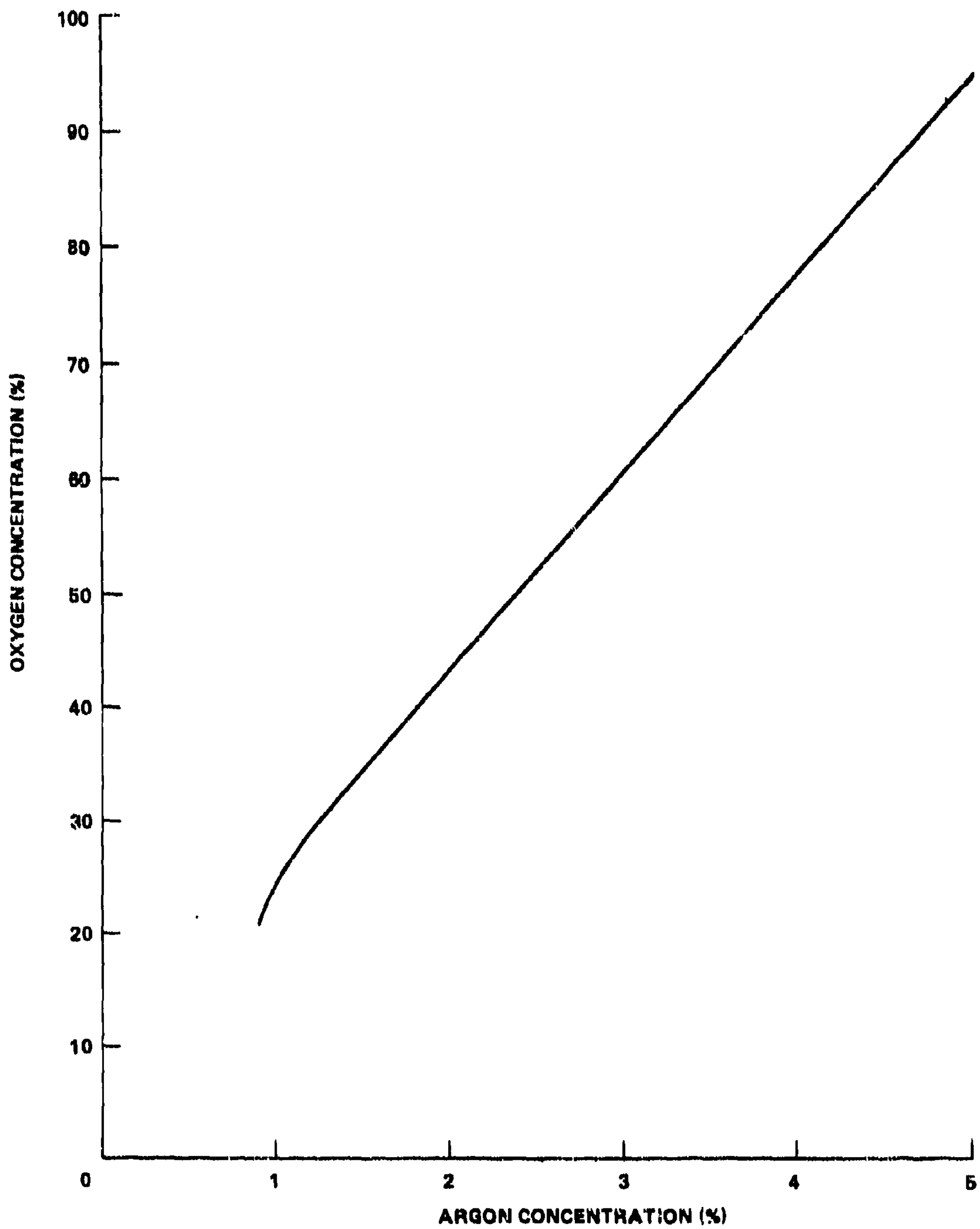


Figure 34 – Oxygen Concentration Vs. Argon Concentration

Table 2

BREATHING GAS FLOWRATES PER MIL-D-19326E

Aircraft Altitude (Feet)	Breathing Gas Flowrate (Liters/Minute)* Unpressurized Cabin		Pressurized Cabin	
	One Man	Two Man	One Man	Two Man
0	13.1	26.2	13.1	26.2
10,000	8.4	16.8	9.6	19.2
20,000	5.4	10.8	7.7	15.4
30,000	3.2	6.4	6.4	12.8
40,000	2.2	4.4	5.0	10.0
50,000	2.2	4.4	3.9	7.8

*NTPD 70°F and 14.7 psia

Table 3

AV-8A EIGHTH STAGE BLEED AIR PRESSURES

Altitude (Feet)	Available Bleed Pressure (Psig)		
	Minimum	Idle Descent at 230 KIAS	Maximum*
0	9.3	13.5	28.0
10,000	19.9	24.5	28.0
20,000	25.3	28.0	28.0
30,000	25.1	28.0	28.0
40,000	21.3	26.7	28.0
50,000	18.3	23.5	28.0

*Due to addition of supply line regulator

Table 4

MAXIMUM DELIVERABLE GAS FLOWRATES PRIOR TO WARNING ACTIVATION

Altitude (Feet)	Inlet Air Pressure[1] (Psig)	Breathing Gas Flowrate (lpm)[2] Warning Activation (mm Hg)		
		210	220	230
0	Minimum	41	31	26
	Idle Descent	70	60	50
	Maximum	70	70	70
10,000	Minimum	46	42	38
	Idle Descent	59	54	49
	Maximum	70	65	58

Table 4 — Continued

Altitude (Feet)	Inlet Air Pressure[1] (Psig)	Breathing Gas Flowrate (lpm)[2] Warning Activation (mm) Hg)		
		210	220	230
20,000	Minimum	39	36	34
	Idle Descent	45	41	38
	Maximum	45	41	38
30,000	Minimum	27	24	21
	Idle Descent	29	26	22
	Maximum	29	26	22
40,000	Minimum	28	25	21
	Idle Descent	29	26	22
	Maximum	30	26	22
50,000	Minimum	18	18	18
	Idle Descent	26	23	20
	Maximum	30	26	22

[1]Based on AV-8A 8th stage.

[2]Referenced to 14.7 psia and 70° F.

Power Consumption

Designed to operate with a power input of 18-29 VDC, oxygen concentrator power consumption for each voltage is presented in Table 5. Also presented are the approximate current draws for the following components: motor, whose drive shaft, through reduction gearing, rotates the system control valve; control electronics, or relays utilized in heater activation; solenoid, activated in low temperature conditions to aid in bed warm up; and two resistance heaters for raising bleed air temperature when required.

The motor, control electronics, and solenoid are all on the same circuit. Heater activation, therefore cannot occur without power to the motor. A variation in current draw with heater #1 vs. heater #2 is due to difference in heater length (number of windings). This is not to say that each concentrator will show some variation. In addition, heater tolerances show that maximum heater power consumption is 575.12 watts (10.27 (2) amps) and 616.54 watts (10.63 (2) amps) at 28 and 29 VDC, respectively.

Activation of both heaters will occur immediately after power is supplied. Both heaters will remain on until inlet air is raised to a temperature of 110-120°F (44-49°C). Heater number 2 will then deactivate, with heater number 1 activating intermittently to maintain this bed inlet air temperature. The on times for heater number 2 before deactivation and intermittent operation of heater 1 depend upon the specific temperature of the air supplied to the unit. An inlet air temperature of 0°F (-17.8°C) at low ambient requires full time activation of both heaters, while the only system power consumption for inlet air above 120° F will be by the motor.

Table 5

OEAS CONCENTRATOR POWER CONSUMPTION

Voltage (DC Volts)	Current (Amps)					Power (Watts)
	Motor	Control Electronics	Solenoid	Heater #1	Heater #2	
29	1.84	0.15	0.31	9.20	9.45	586.3
28	1.92	0.15	0.30	8.90	9.10	570.4
27	1.95	0.15	0.29	8.50	8.75	550.2
26	2.00	0.15	0.28	8.20	8.40	533.4
25	2.10	0.15	0.27	7.85	8.10	518.0
24	2.05	0.15	0.26	7.50	7.70	495.6
23	1.82	0.15	0.25	7.20	7.45	473.8
22	1.62	0.15	0.24	6.90	7.10	450.0
21	1.45	0.15	0.22	6.55	6.75	425.6
20	1.32	0.15	0.21	6.25	6.45	405.2
19	1.22	0.15	0.20	5.95	6.20	387.0
18	1.18	0.15	0.19	5.60	5.80	364.8

It should be noted that all oxygen concentration tests, unless specified otherwise, are conducted with "house air" inlet temperature (60-80°F) (16-27°C). This translates to initial operation of both heaters, then a maximum current draw of 8.90 amps with intermittent operation of heater 1, and a bed inlet air temperature of 110-120°F. In addition, initial motor circuit power consumption can show solenoid activation during periods when not normally required (60-80°F ambient; 60-80°F inlet air) due to variances in set point from unit to unit. As an example, solenoid activation with turn on at standard conditions can occur for approximately 10 minutes with an inlet pressure of 25 psig. Solenoid activation is eivdent not only through the increase in power consumption, but through the sound of "warm up" air (approximately 25 lpm) dissipating within the thermal shroud.

The OEAS Oxygen Concentrator showed no variation in the values presented in Figure 31 or variation in cycle time, with voltages of 18-29 volts supplied to the motor.

Operation at Altitude

The oxygen concentrator was verification tested for purity delivered at altitudes of 10, 20, 30, 40 and 50000 feet. As mentioned previously, the entire unit was exposed to the ambient pressures specified with the nitrogen enriched exhaust venting directly to these altitudes. A 250 point test matrix was conducted with variation of altitude (aircraft), inlet air pressure, and breathing gas flowrate. Included in the analysis are breathing gas flowrates based on the Harrier pressurization schedule of Figure 35 and the corresponding breathing gas flowrates of Figure 36. All flowrates in the test program are referenced to sea level conditions of temperature and pressure. Analysis was also based on the bleed air pressures of Table 3, with all test pressures referenced to the particular test altitude. All testing was conducted at standard temperature, with an inlet air temperature of 110-120°F (43-49°C) (power applied to heaters).

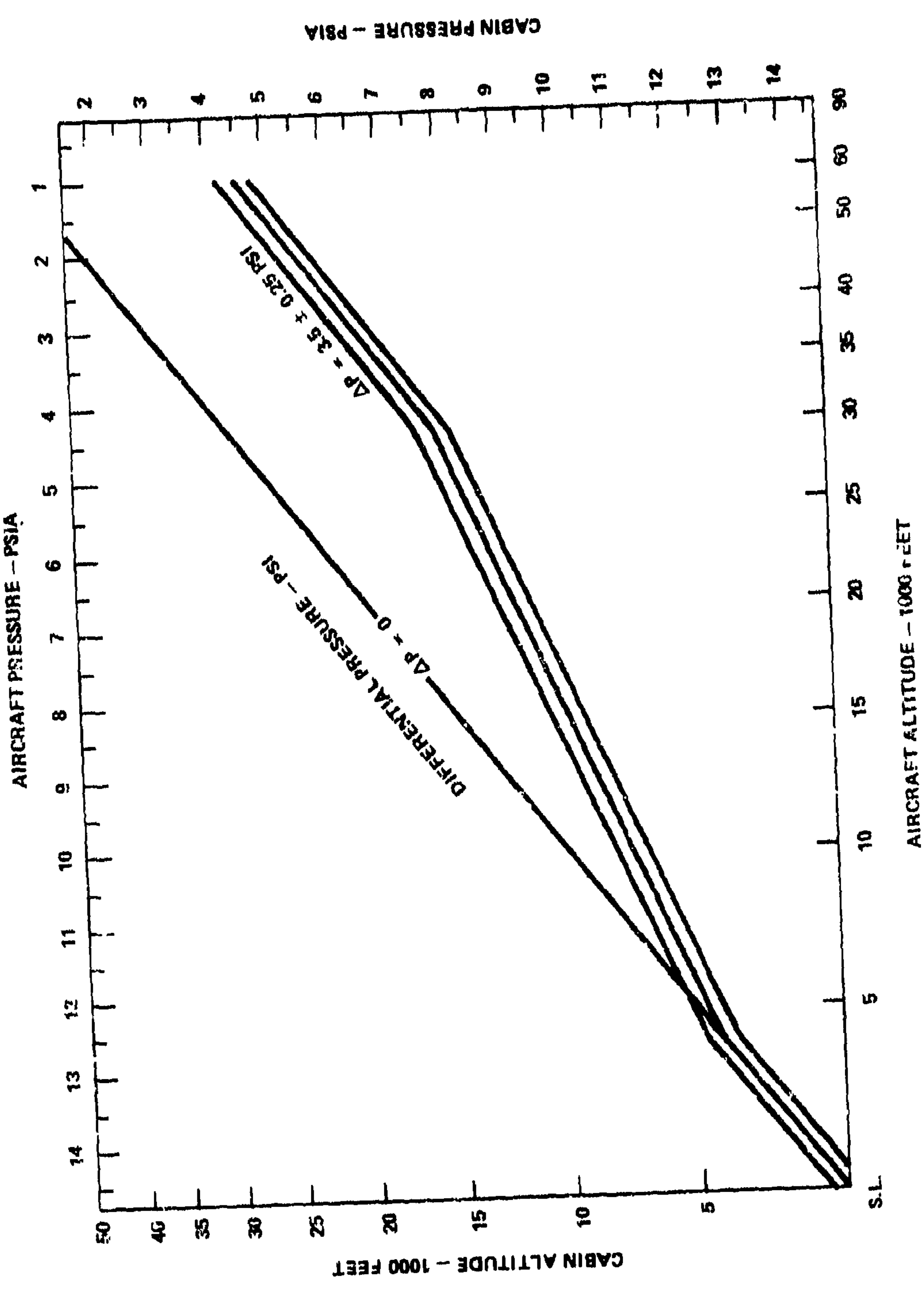


Figure 35 — Harrier Cabin Pressurization Schedule

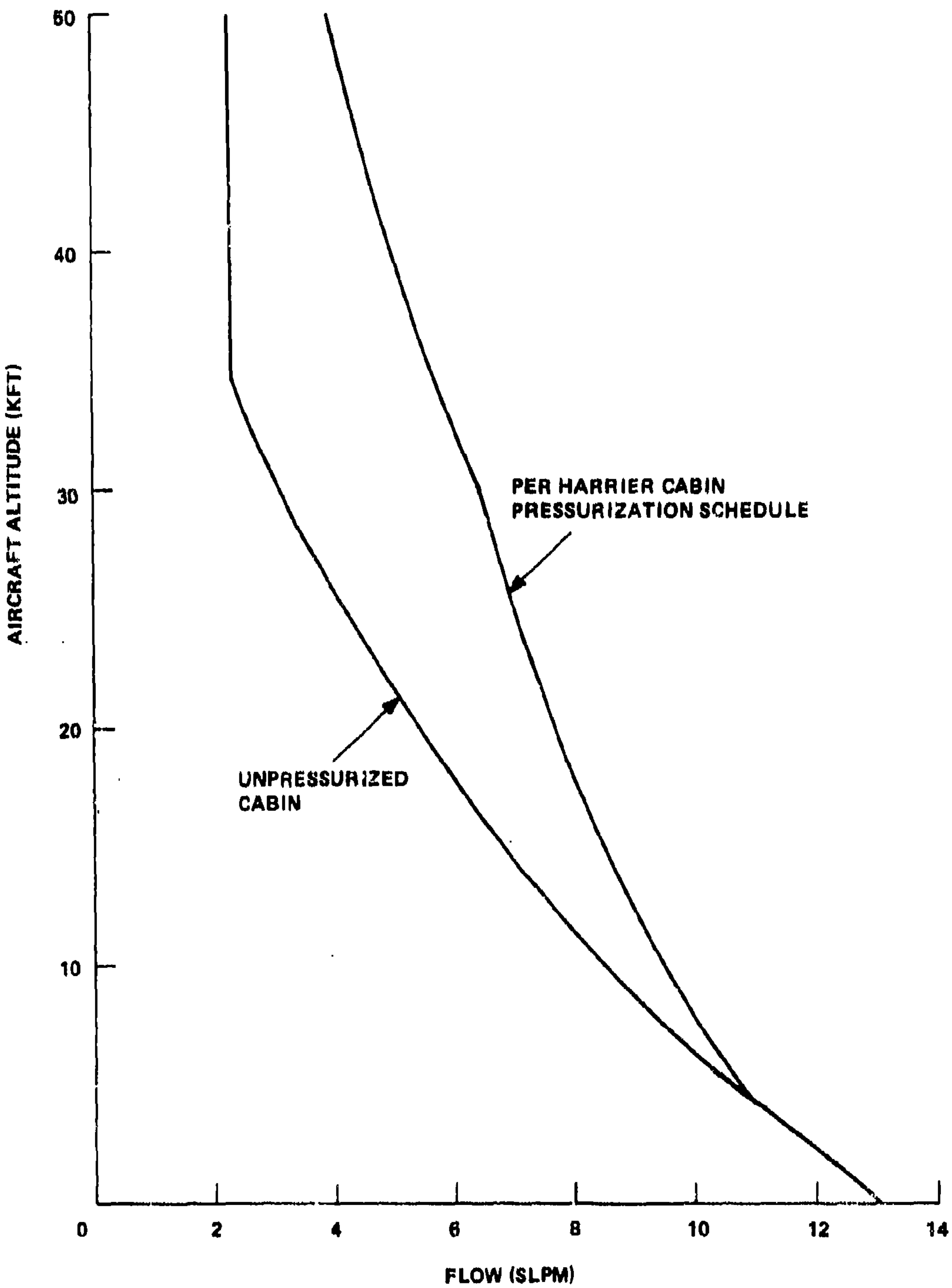


Figure 36 – One Man Breathing Rate Per MIL-D-19326E

Inlet air flowrates for various altitudes are presented in Figure 37, showing the relative reduction in consumption with ascent in altitude. Results for testing for oxygen concentrations delivered are presented in various methods in the figures following. Figures 38 through 42 show oxygen concentration vs. outlet flowrate for various inlet pressures at altitudes of 10 through 50,000 feet, respectively. As seen from these results, oxygen concentration increases with inlet air pressure and altitude (nitrogen exhaust pressure). Concentration also decreases with an increase in breathing gas flowrate, except for low flowrates which, due to a more efficient concentration of argon, actually deliver less oxygen purity than higher flowrates. Maximum oxygen concentration was found with outlet gas flowrates of approximately 8-18 lpm. The amount of argon concentration with lower flowrates can be estimated by taking the difference between the oxygen concentration delivered and 95 percent oxygen, and adding this difference to 5 percent argon. Also depicted in these figures is the average warning activation point (220 mm Hg with activation at 89.1 percent oxygen at 28,000 feet or above). Again, the maximum deliverable flowrates prior to warning activation are presented in Table 4.

Figures 43 through 47 depict oxygen concentration vs. inlet pressure for various breathing gas flowrates at altitudes of 10 through 50,000 feet. The effect of increasing inlet air pressure on increasing oxygen concentration can be seen from these plots. The relative effect of increasing altitude (and therefore bed inlet and exhaust pressure differential) on increasing oxygen concentration for all flowrates is presented in Figure 48. With the realization that increasing this pressure differential leads to more efficient concentrator operation, it should also be mentioned that an adverse effect will result with excessive back pressure on the nitrogen vent port. Early developmental tests have shown that the resistance to this exhaust should be no more than that equivalent to 4 feet of straight tube.

Figures 49, 50 and 51 analyze concentrator performance within the operational envelope of the AV-8A. Results were favorable, with adequate concentrations delivered for one or two man flowrates with minimum, idle descent and maximum (28 psig) inlet pressures. Figures 52 through 55 present oxygen concentration vs. altitude for flowrates of 13.1, 26.2, 35 and 50 lpm (NTP), respectively, for various inlet pressures.

High Temperature

The oxygen concentrator was high temperature tested through exposure to 185°F for a period of 16 hours. The unit was non-operational throughout this period (no inlet air or power applied). After a stabilization at standard temperature, the concentrator was verification checked for normal operation. The concentrator showed no degradation with respect to oxygen concentration delivered, power consumption, cycle time, outlet pressure or any structural degradation as a result of the high temperature exposure.

Operational tests were conducted with high temperature inlet air at an ambient temperature of 160°F (71°C). The procedure for each of these tests was common, with a four hour high temperature "soak" (non-operating) at 160°F, followed by four hours of operation with high temperature inlet air while maintaining the high ambient temperature. Tests were conducted with the maximum design inlet air temperature of 250°F (121°C) with inlet pressures of 28 and 40 psig and with an inlet air temperature of 160°F and an inlet pressure of 28 psig. Outlet flowrate was held at a constant 13.1 lpm throughout each test. Performance was found to decrease with increased inlet air temperature and with lower inlet air pressure. The performance degradation, however, was not sufficient enough to result in a warning light activation. The corresponding inlet air flowrates were measured at the conclusion of the four hour operating period, the values of which are presented in Figure 57. A decrease in molecular sieve absorption capacity can be seen with the drop in inlet air flowrate. Various temperatures of interest with analysis during high temperature operation were recorded. This data, showing a variation of temperature with time, is presented

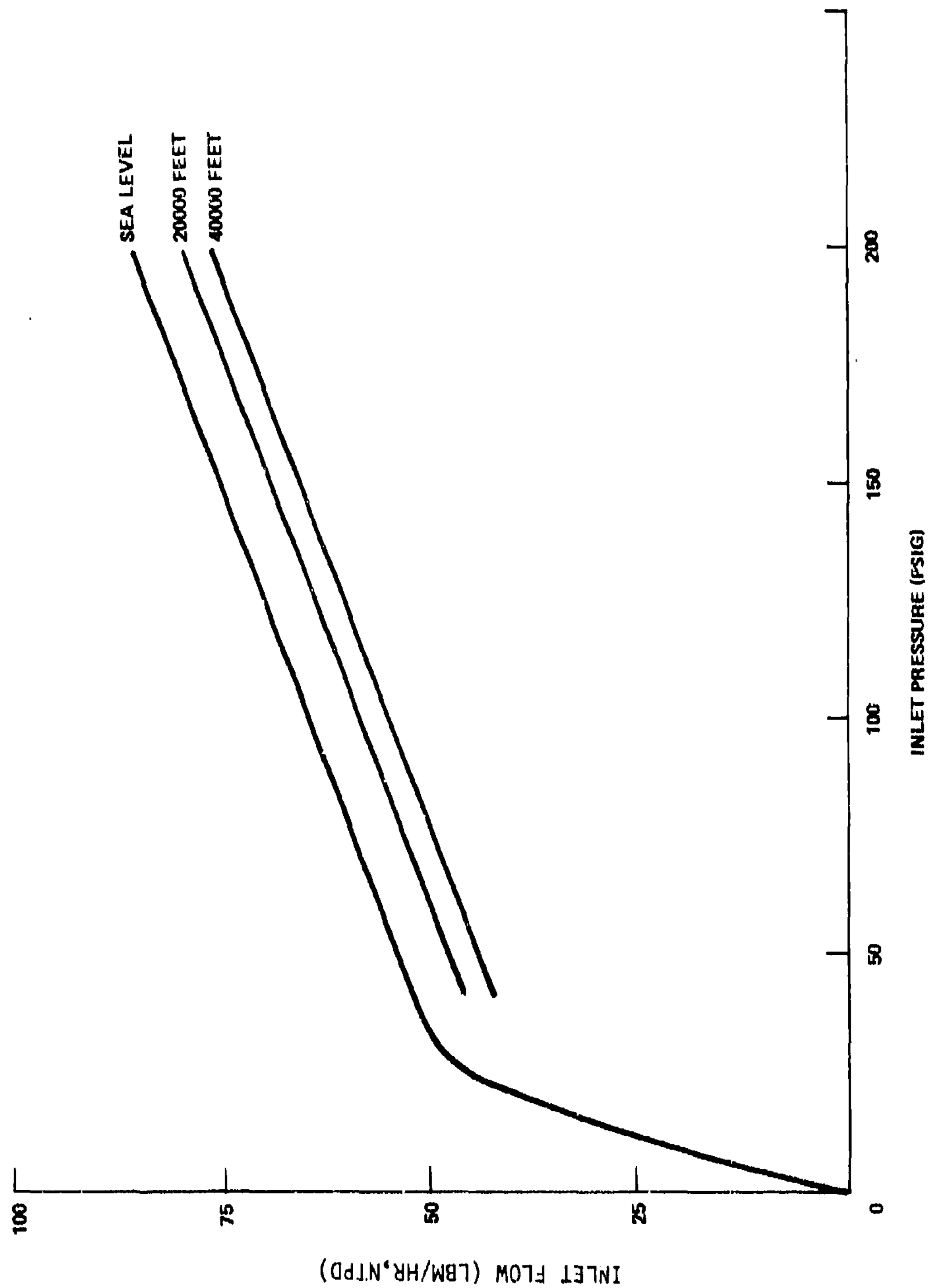


Figure 37 — OEAS Concentrator Inlet Flow Vs. Inlet Pressure At Altitude

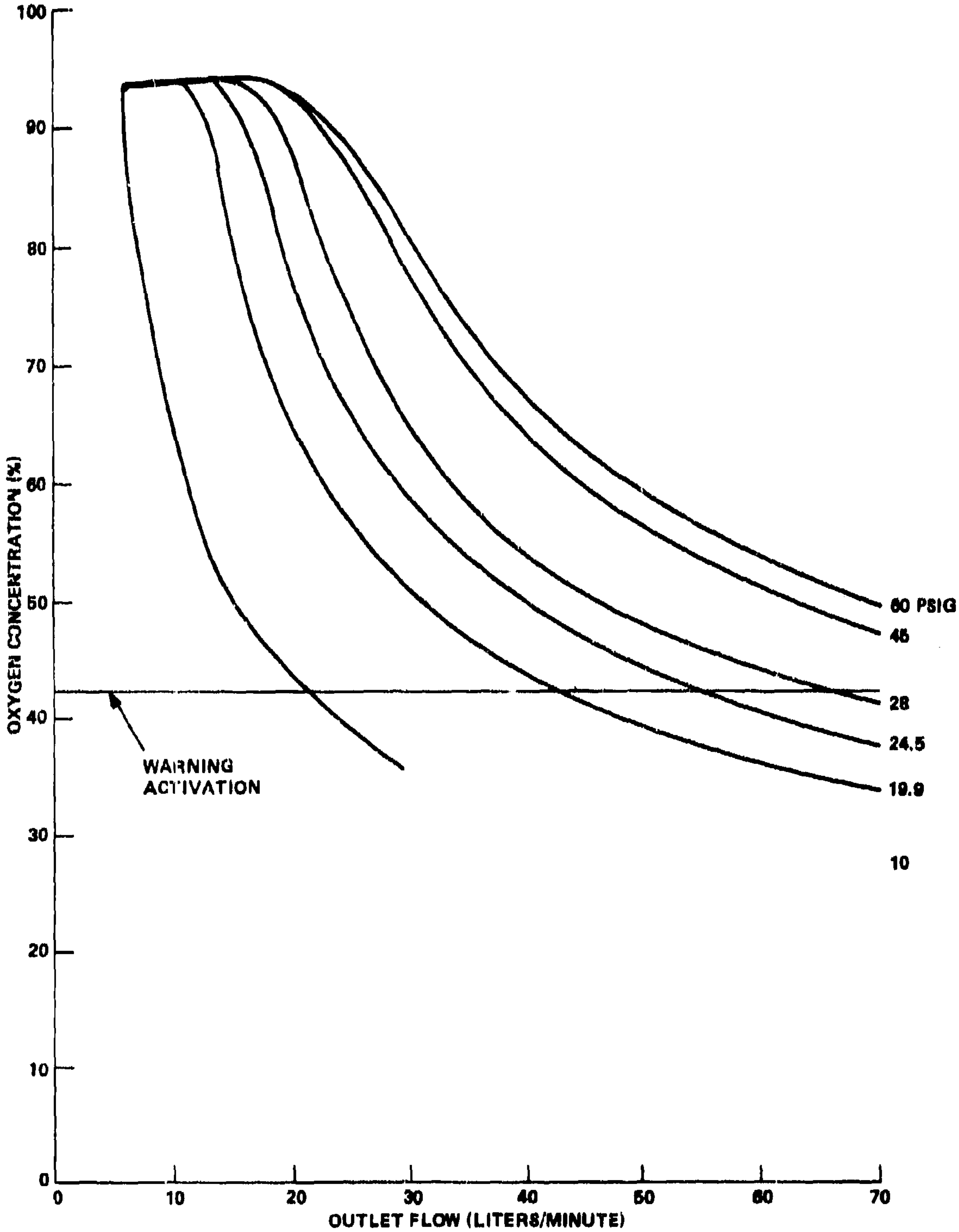


Figure 38 — Oxygen Concentration Vs. Outlet Flow for Various Inlet Pressures at 10,000 Feet

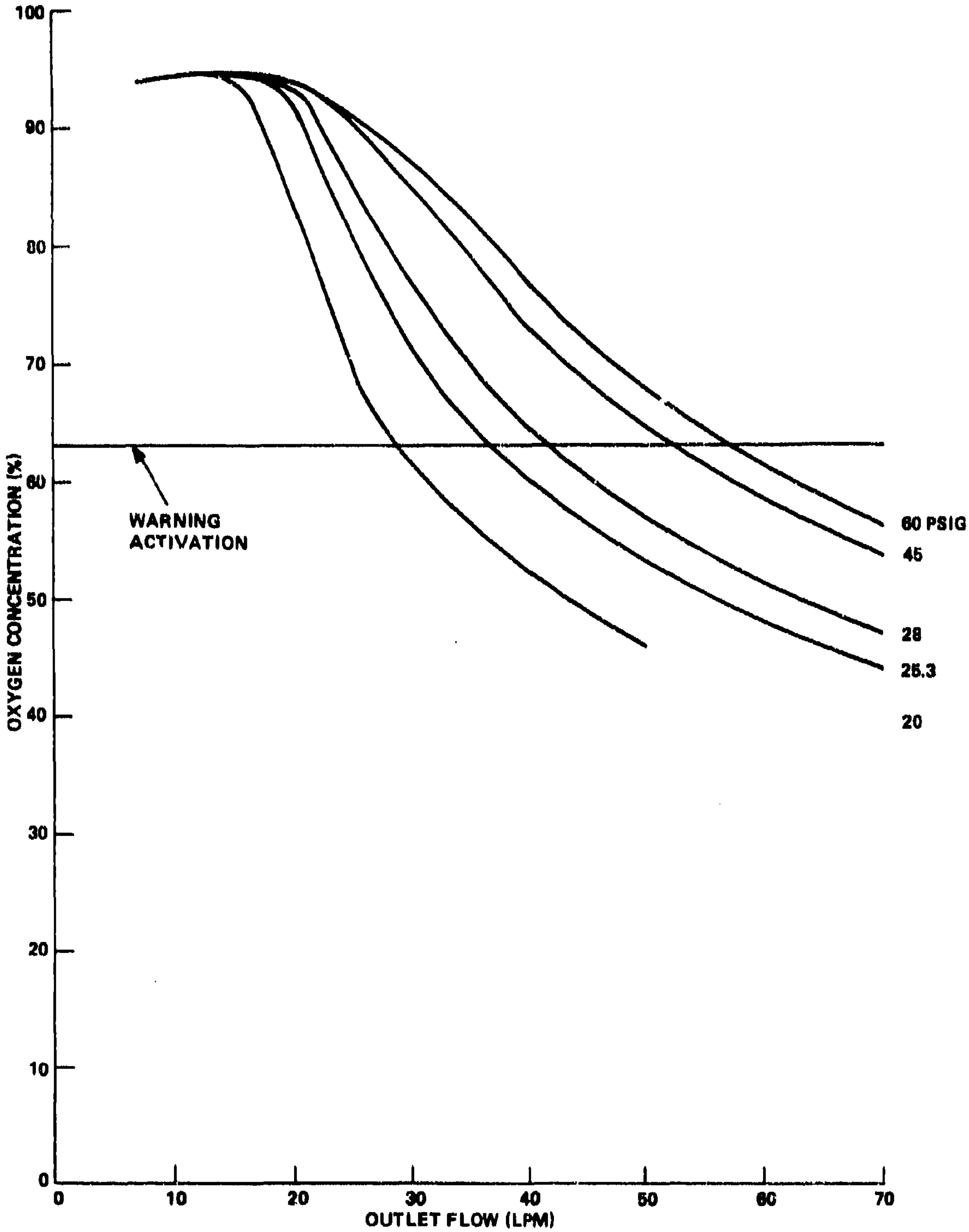


Figure 39 – Oxygen Concentration Vs. Outlet Flow for Various Inlet Pressures at 20,000 Feet

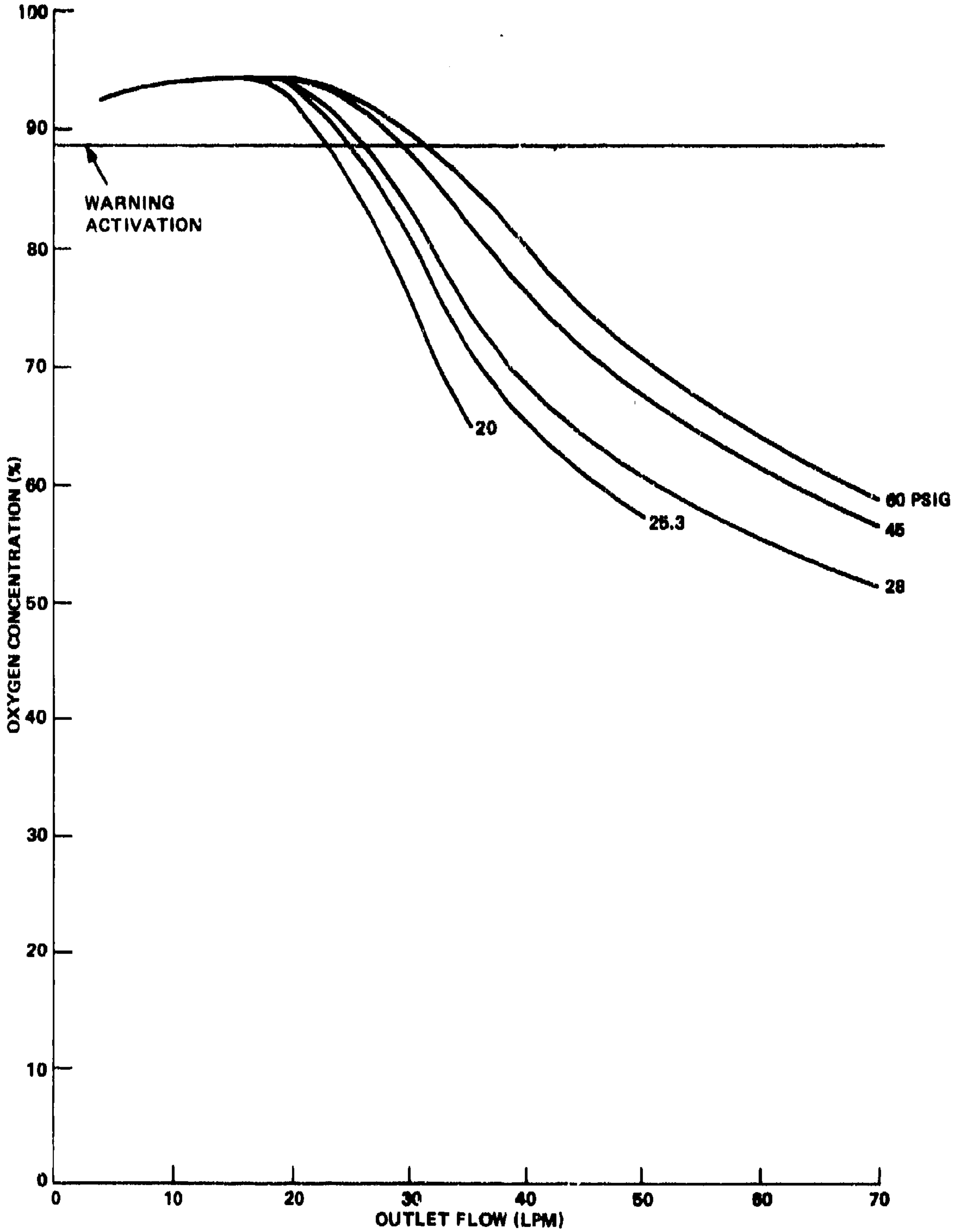


Figure 40 – Oxygen Concentration Vs. Outlet Flow for Various Inlet Pressures at 30,000 Feet

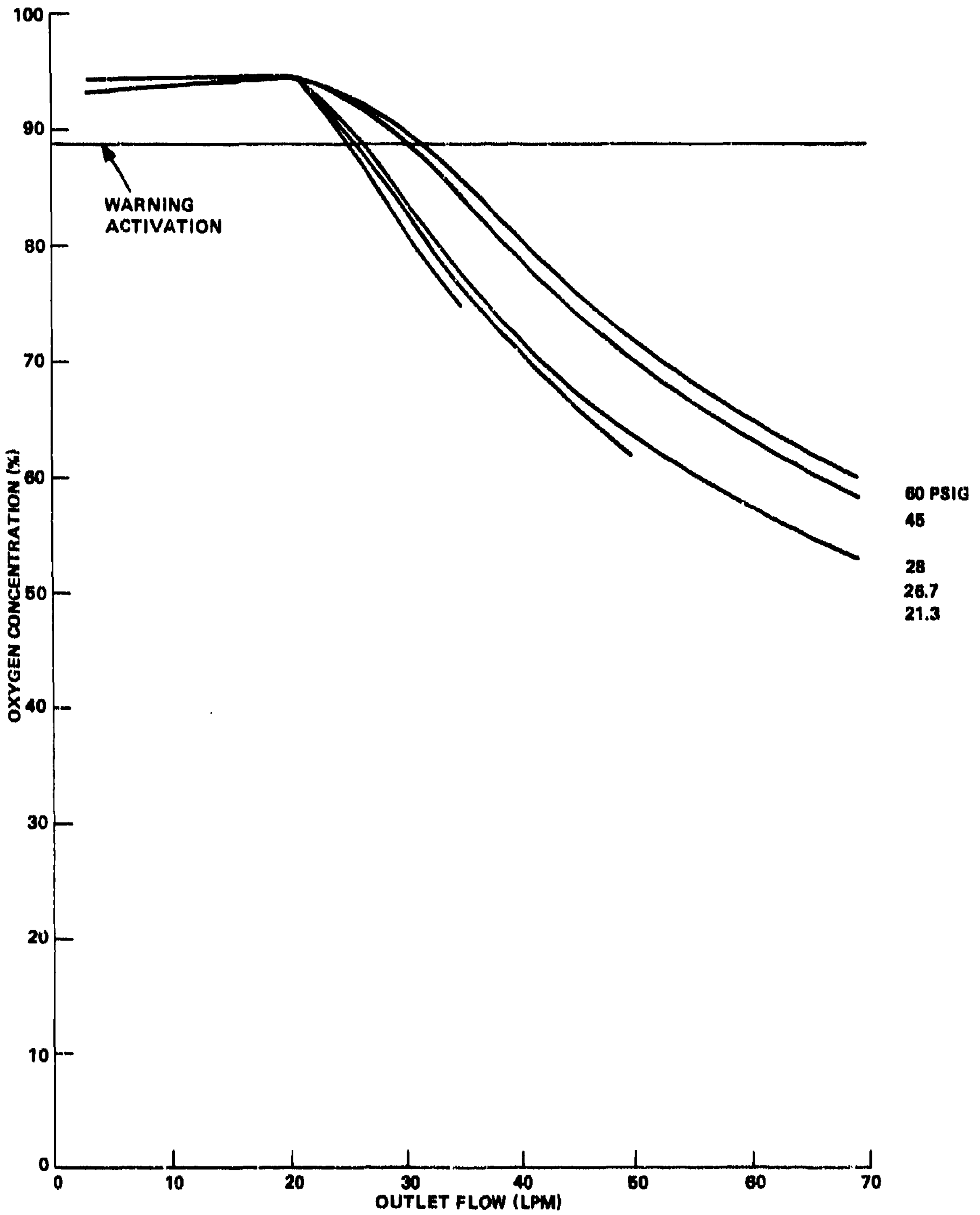


Figure 41 — Oxygen Concentration Vs. Outlet Flow for Various Inlet Pressures at 40,000 Feet

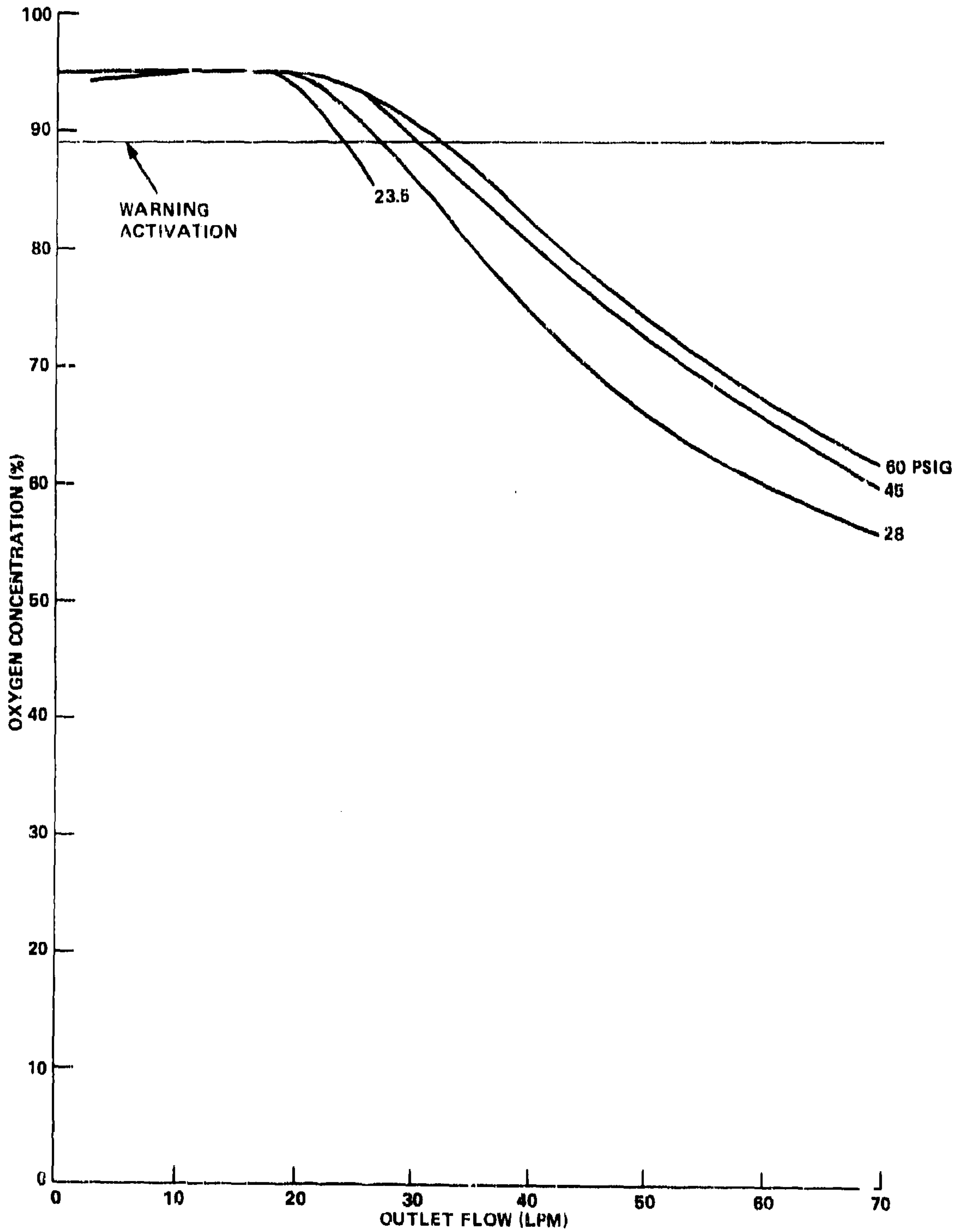


Figure 42 – Oxygen Concentration Vs. Outlet Flow for Various Inlet Pressures at 50,000 Feet

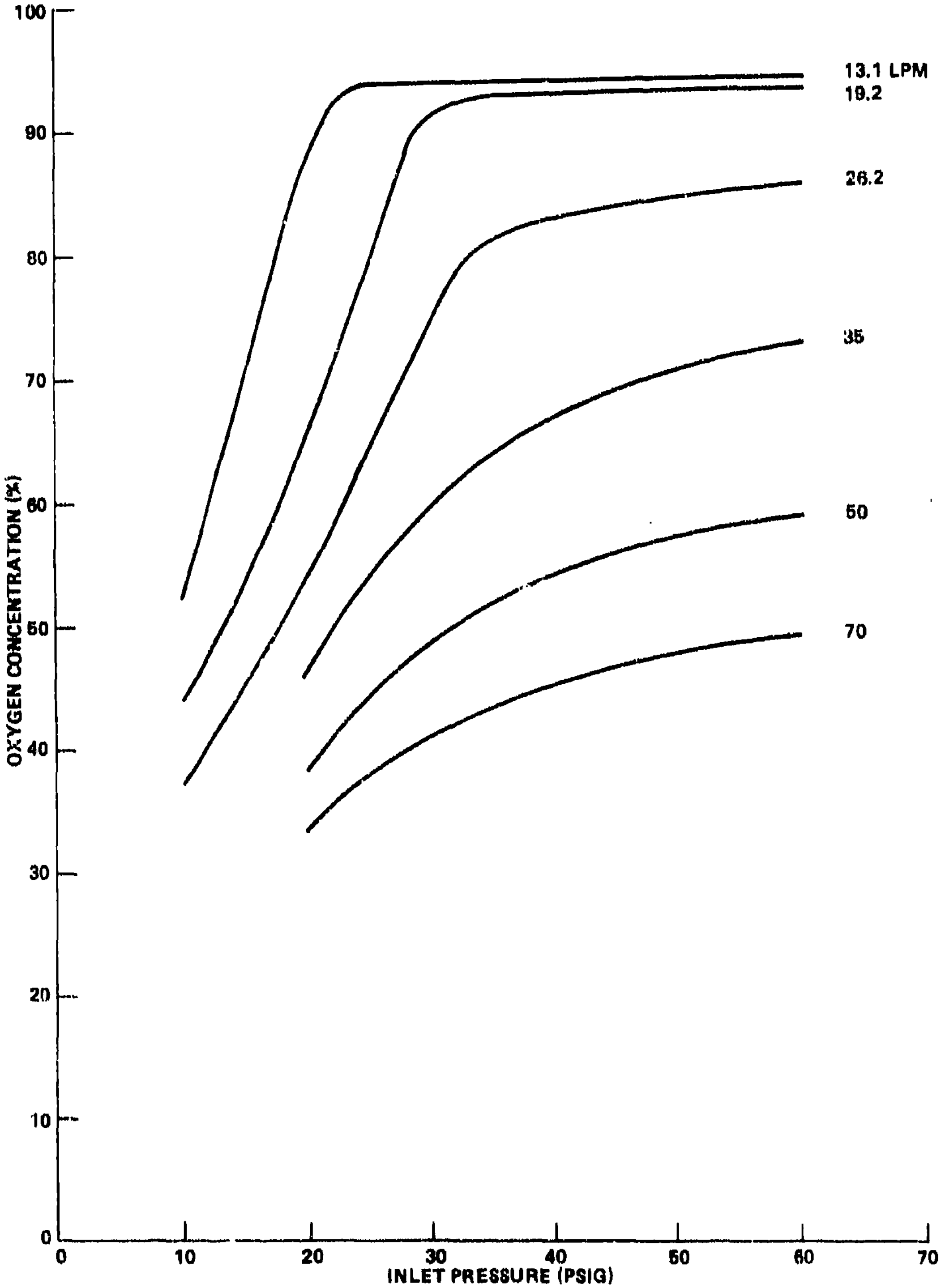


Figure 43 – Oxygen Concentration Vs. Inlet Pressure at 10,000 Feet

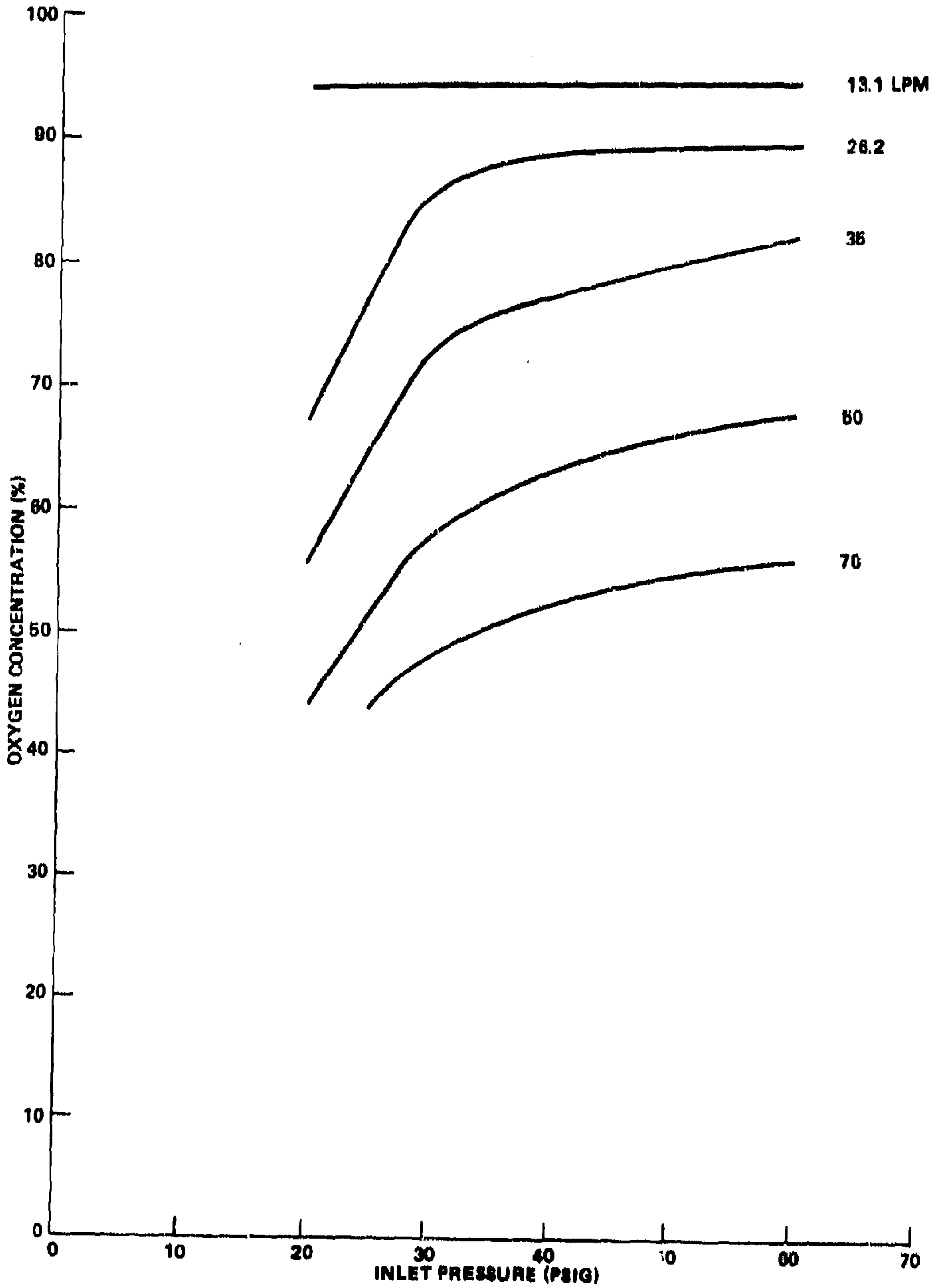


Figure 44 – Oxygen Concentration Vs. Inlet Pressure at 20,000 Feet

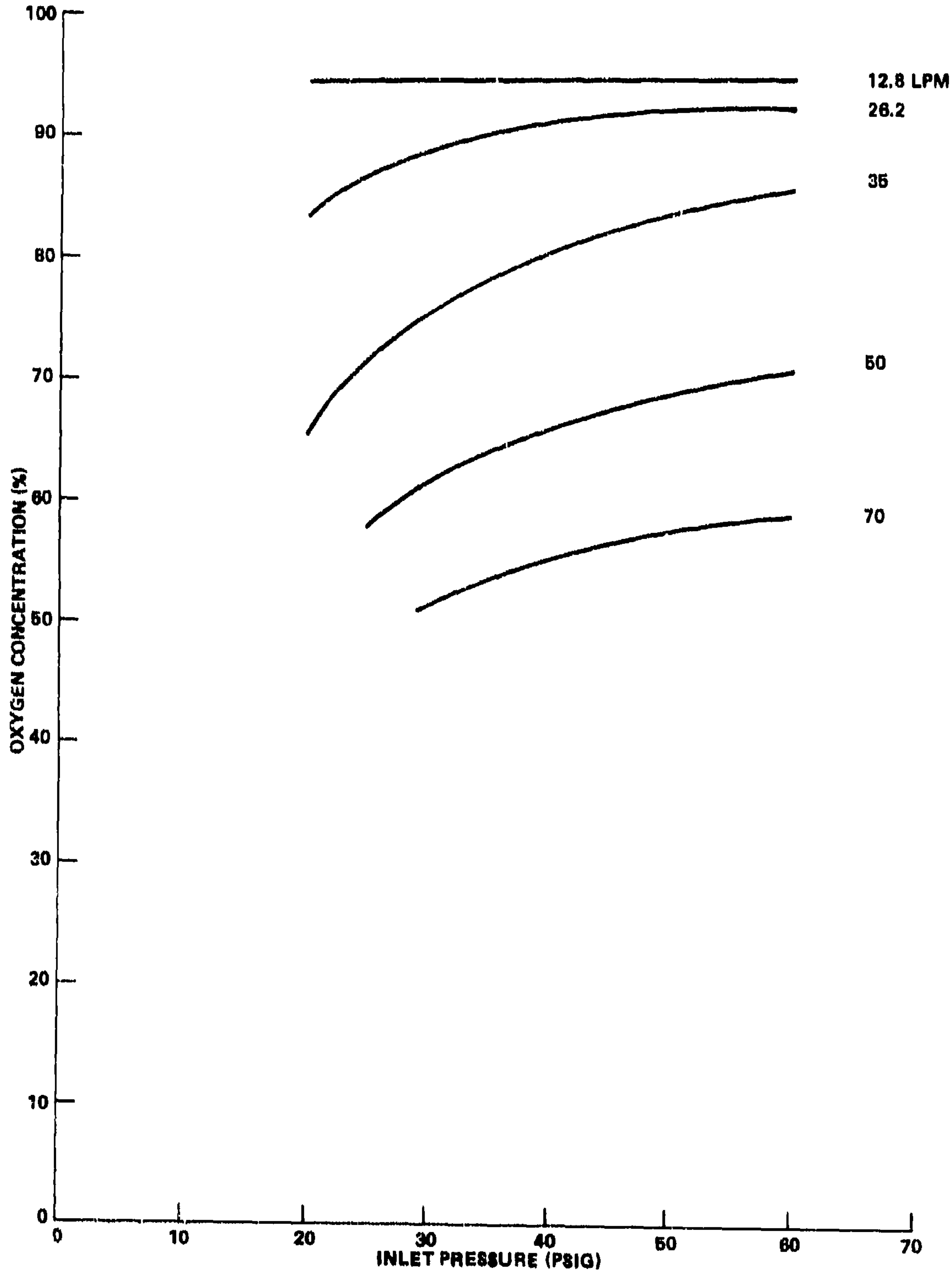


Figure 45 — Oxygen Concentration Vs. Inlet Pressure at 30,000 Feet

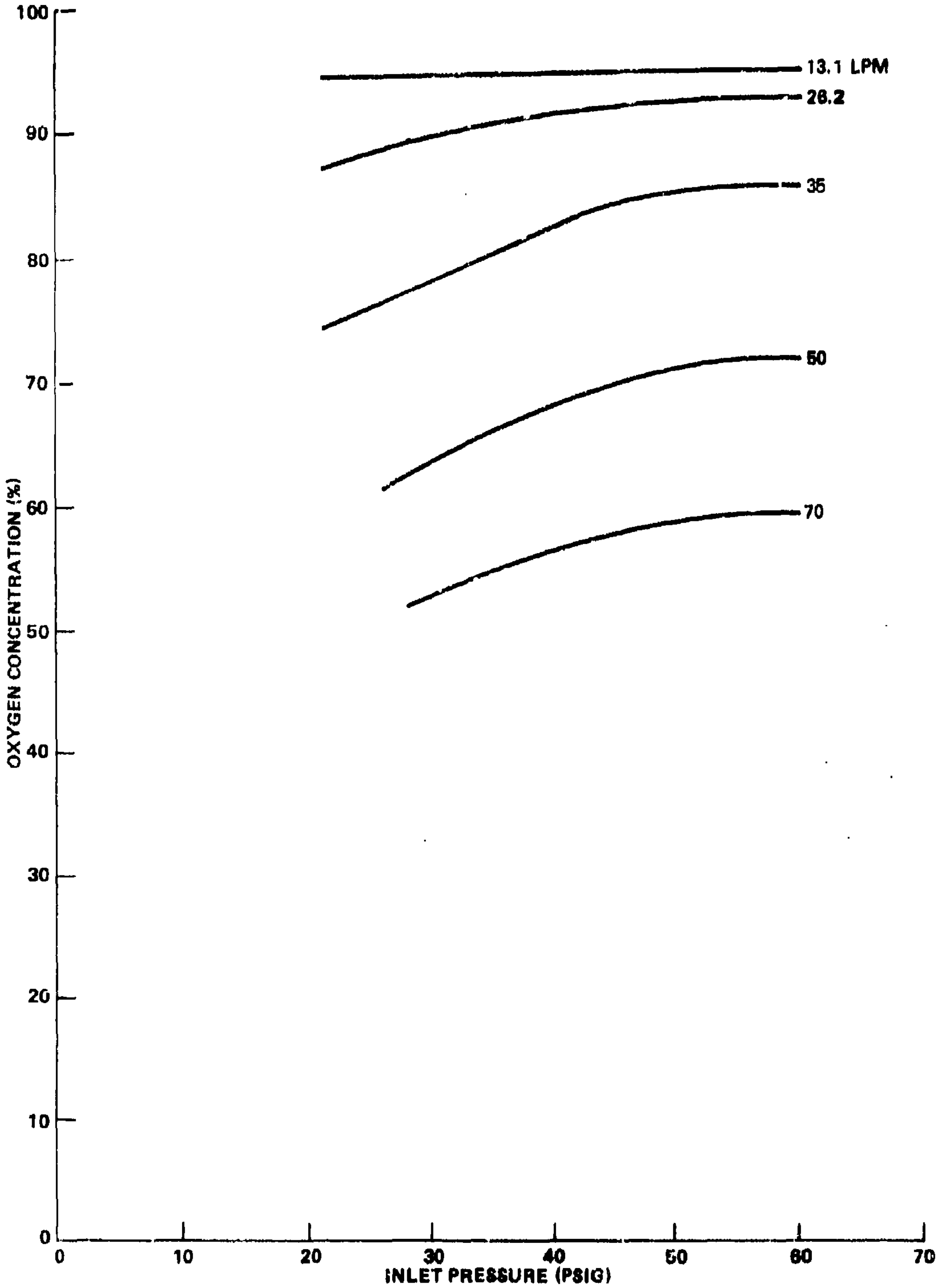


Figure 46 – Oxygen Concentration Vs. Inlet Pressure at 40,000 Feet

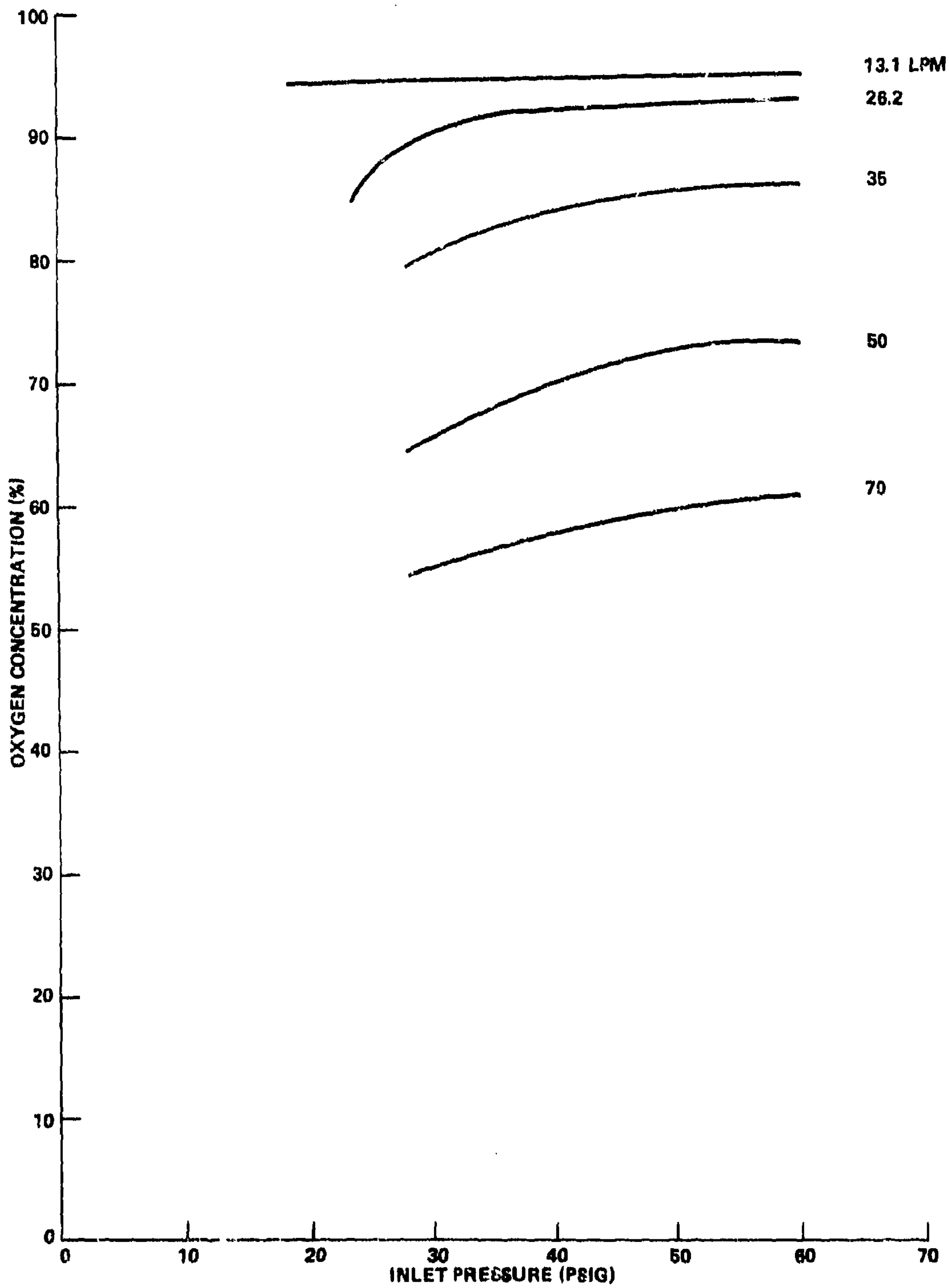


Figure 47 — Oxygen Concentration Vs. Inlet Pressure at 50,000 Feet

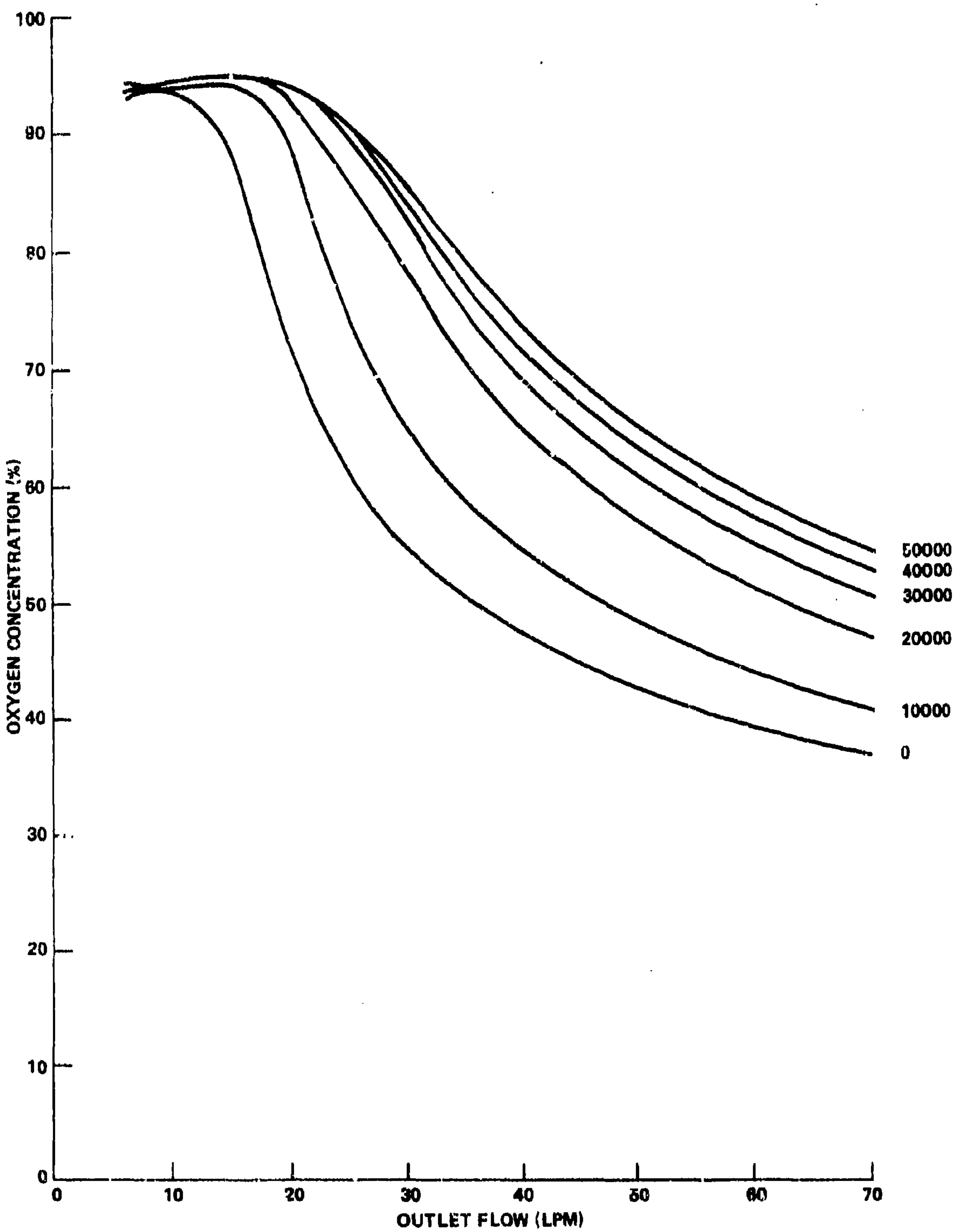


Figure 48 — Oxygen Concentration Vs. Outlet Flow for 28 Psig Inlet Pressure at all Altitudes

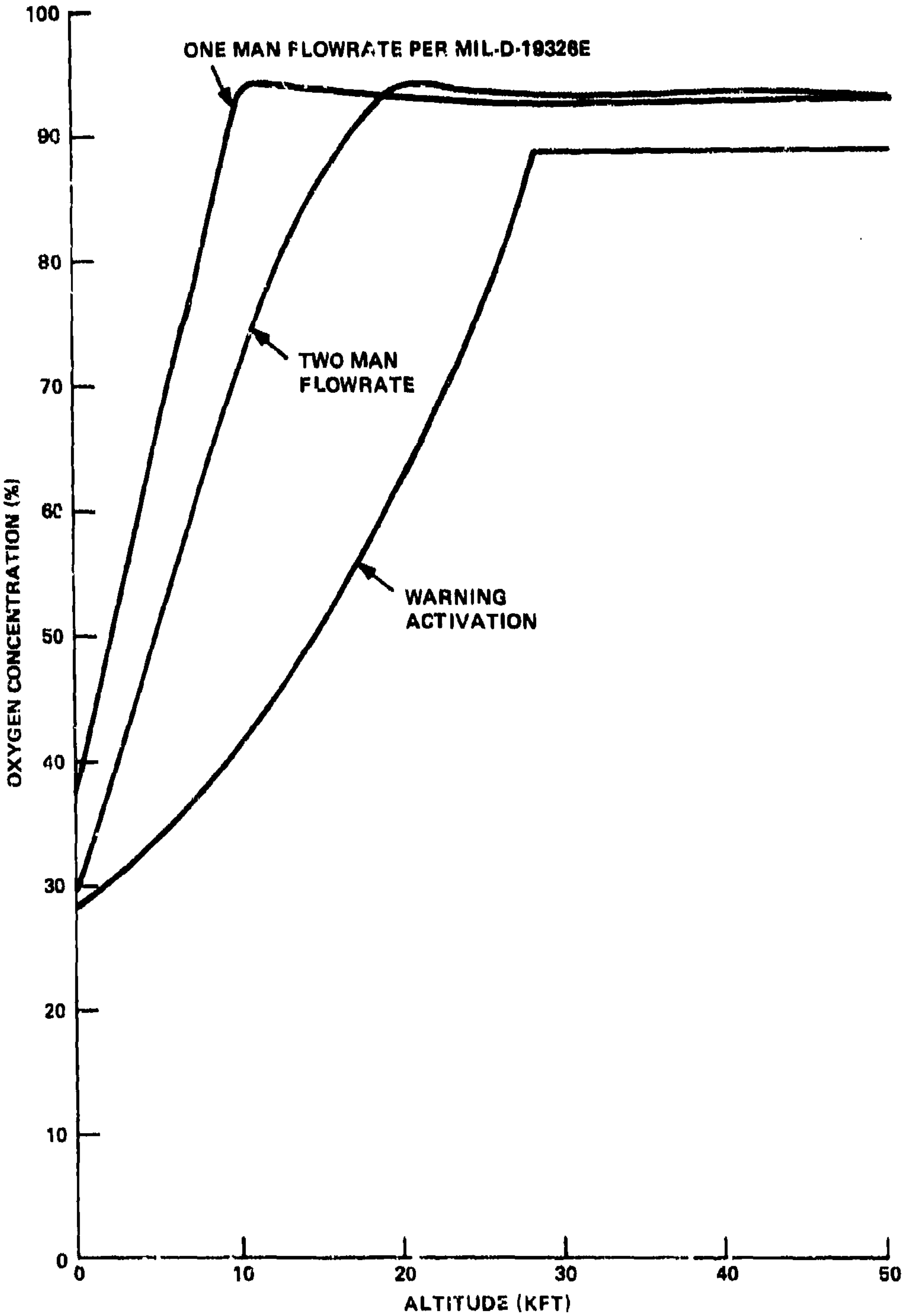


Figure 49 – Oxygen Concentration Vs. Outlet Flow for One and Two Man Flowrates; Minimum Inlet Pressure

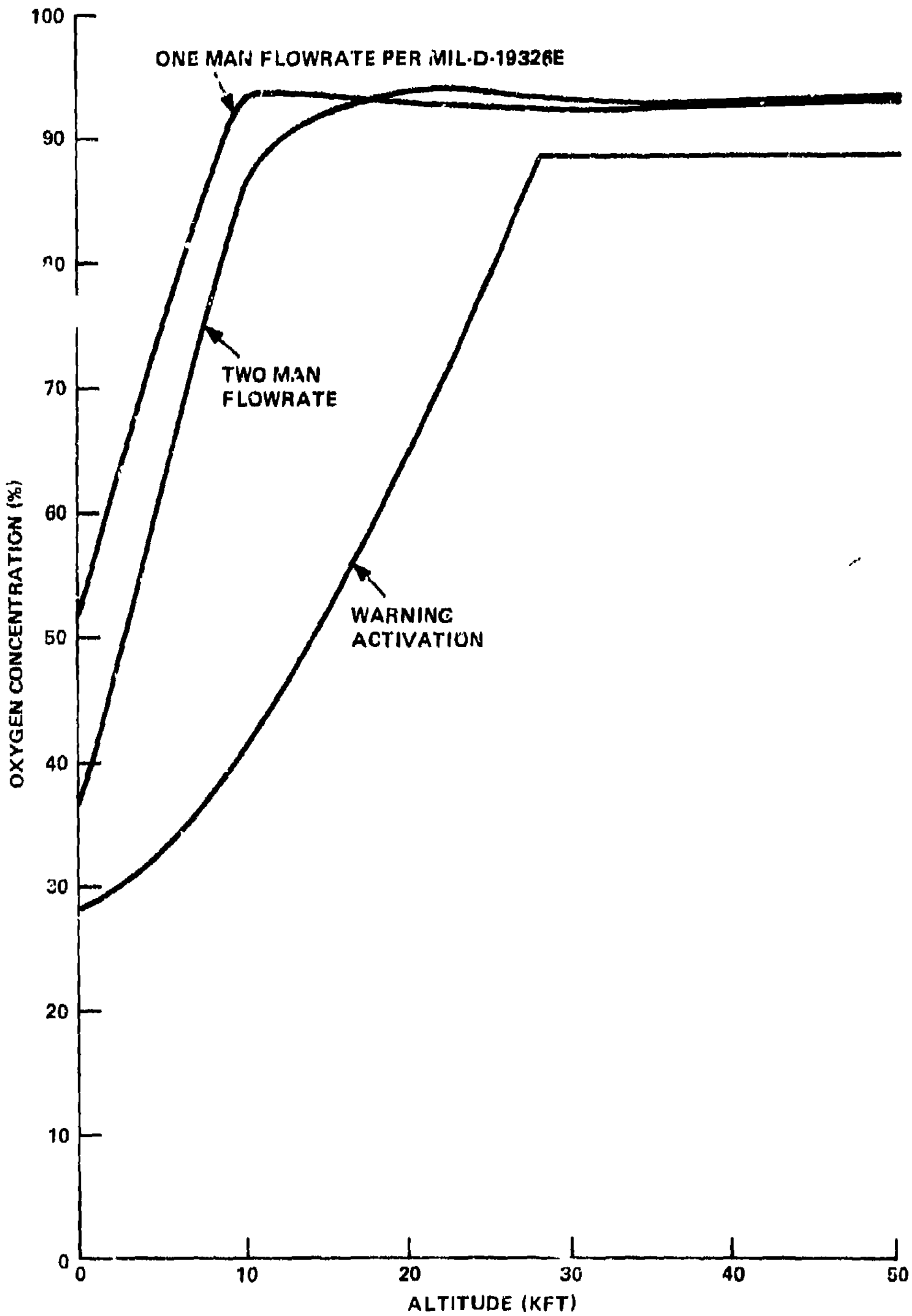


Figure 50 – Oxygen Concentration Vs. Altitude for One and Two Man Flowrates; Idle Descent Inlet Pressures

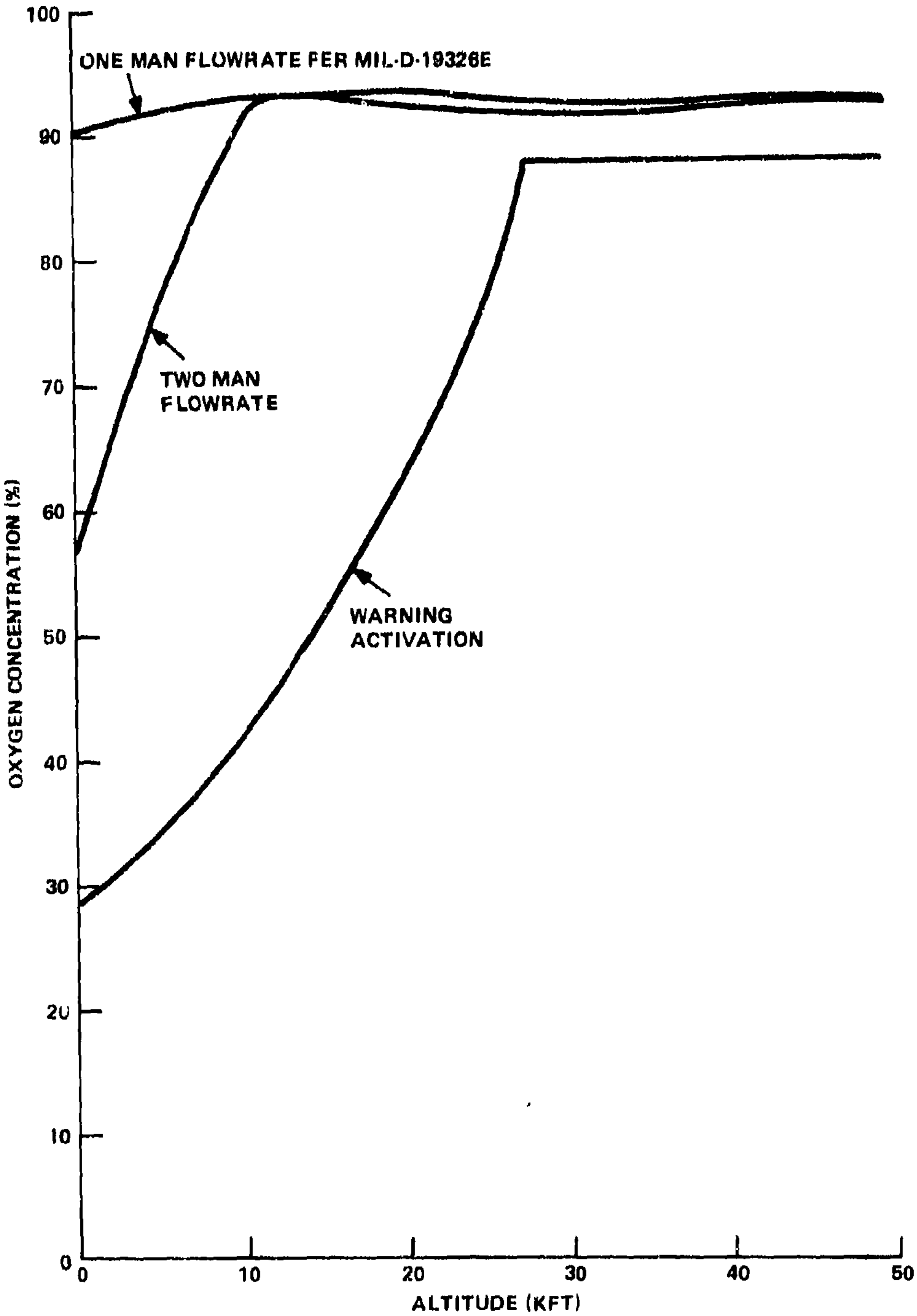


Figure 51 – Oxygen Concentration Vs. Altitude for One and Two Man Flowrates; Maximum Inlet Pressure

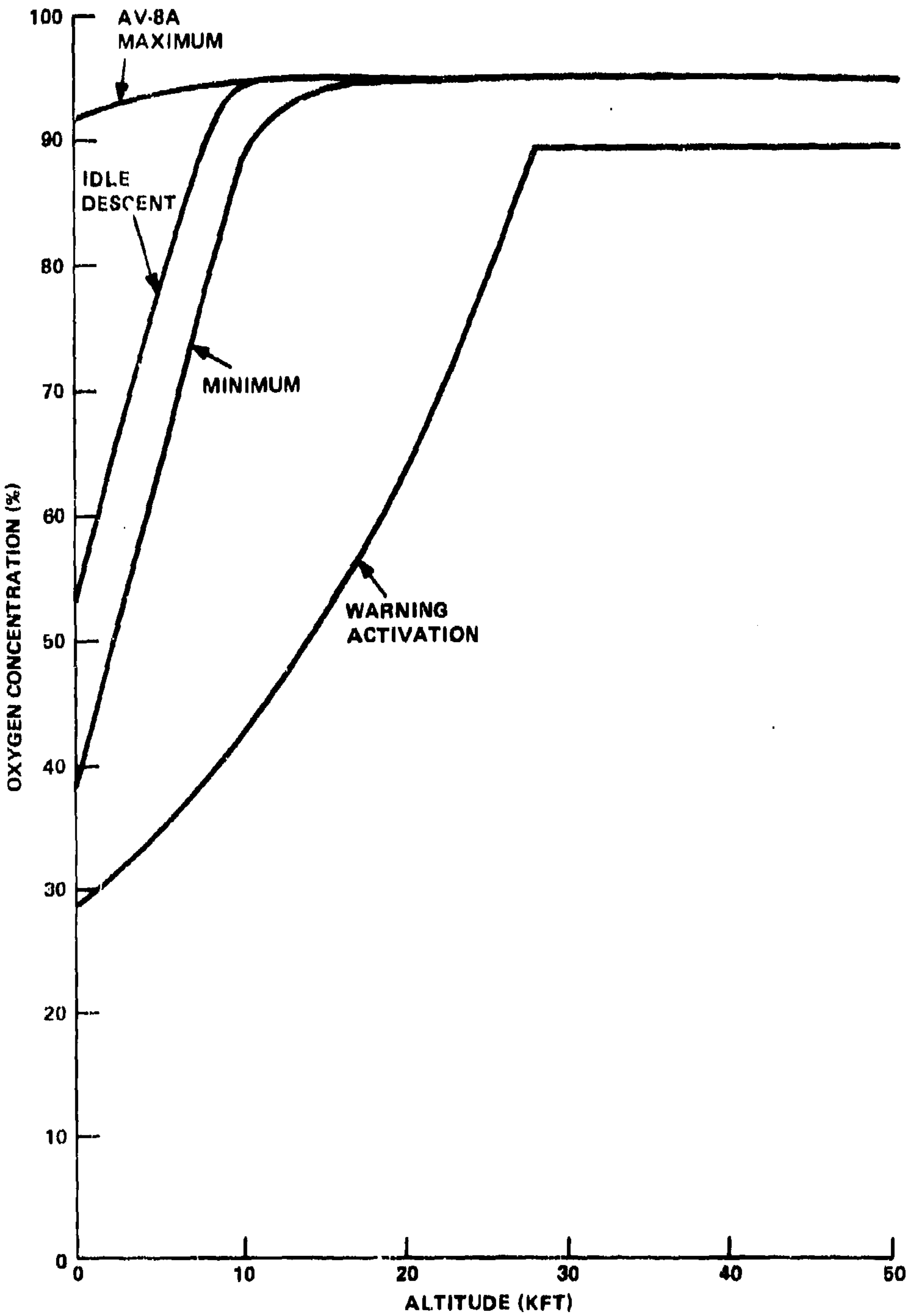


Figure 52 — Oxygen Concentration Vs. Altitude (13.1 lpm Outlet Flowrate)

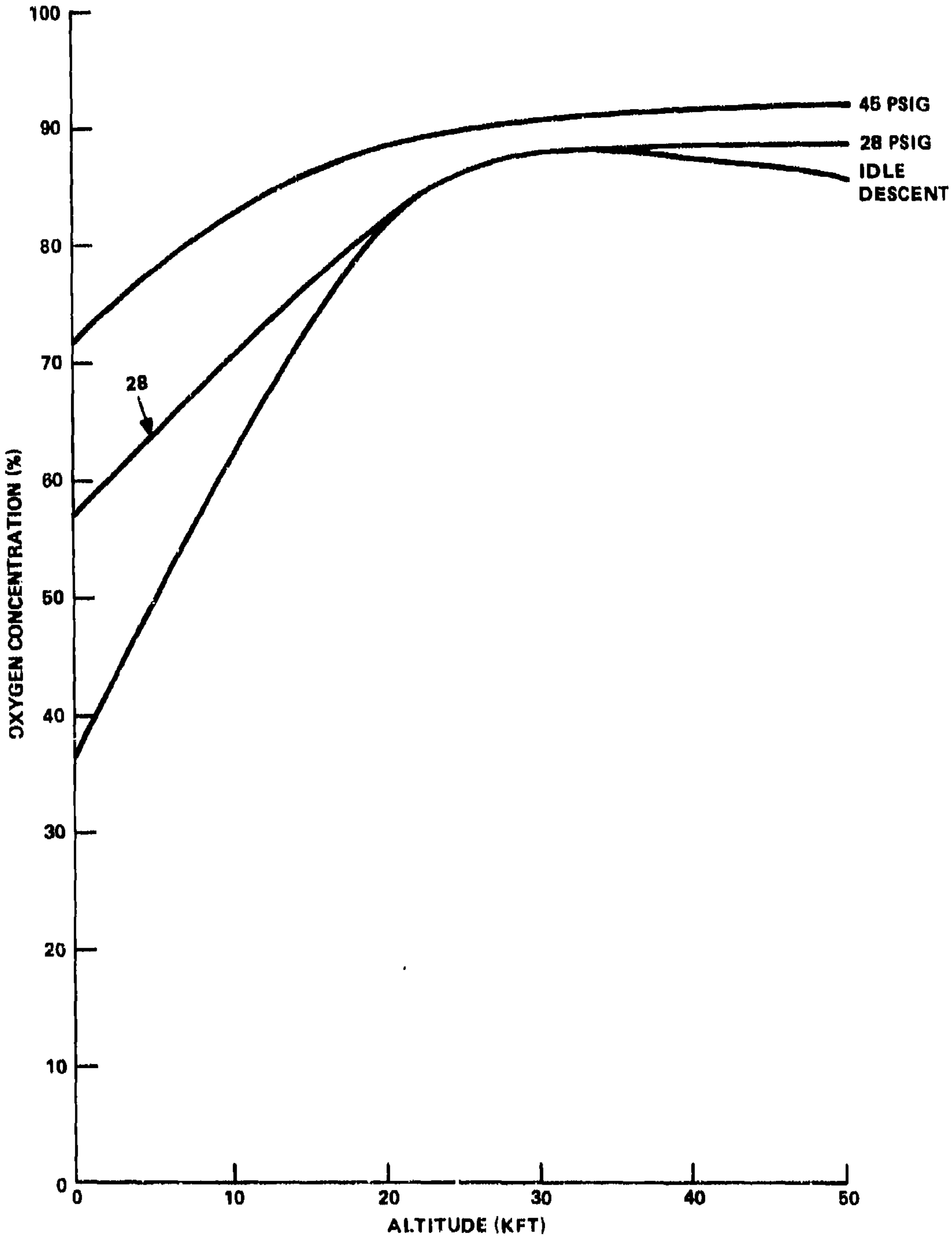


Figure 53 — Oxygen Concentration Vs. Altitude for Various Inlet Pressures; 26.2 lpm Outlet

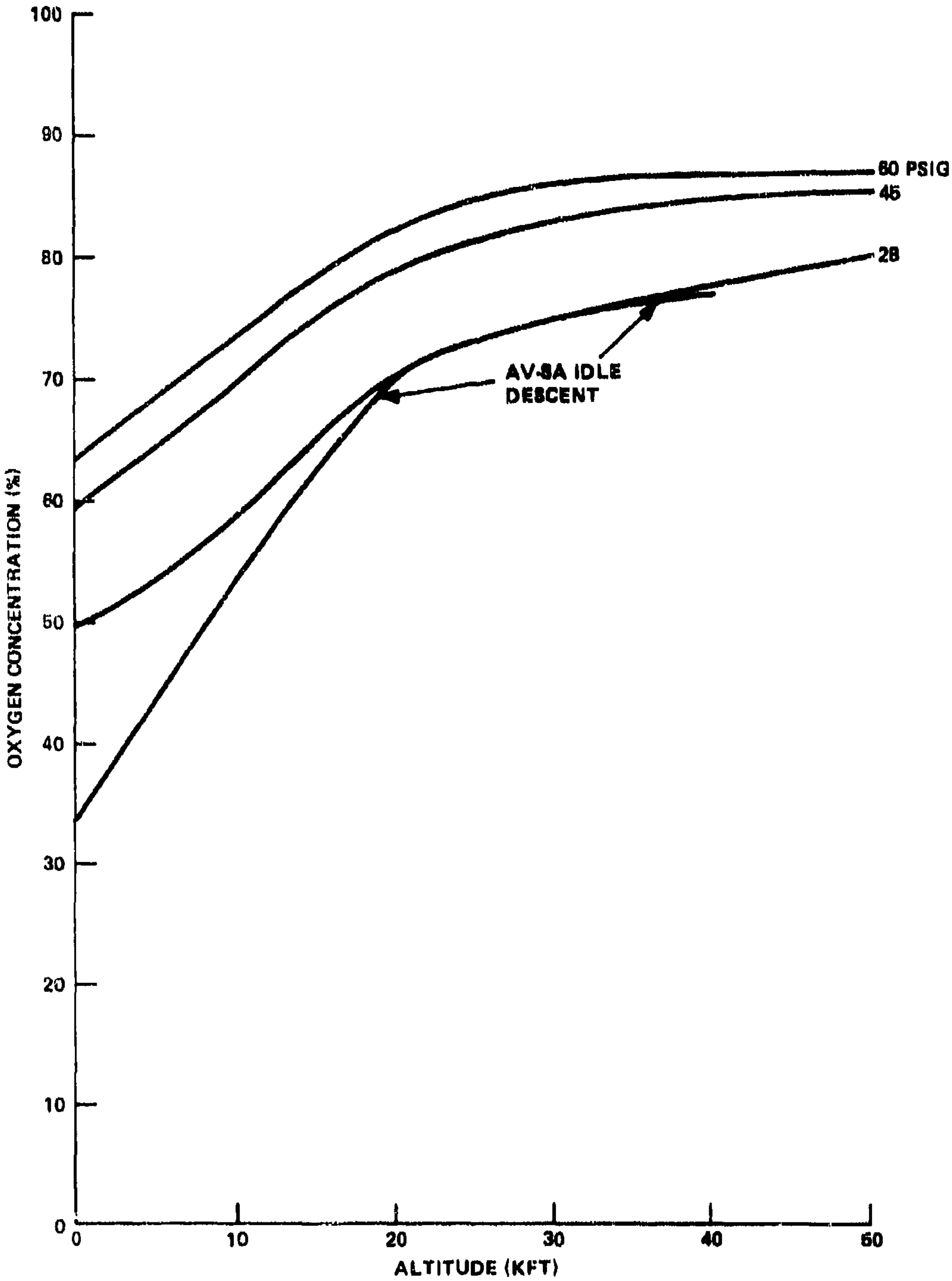


Figure 54 — Oxygen Concentration Vs. Altitude (35 lpm Outlet Flowrate)

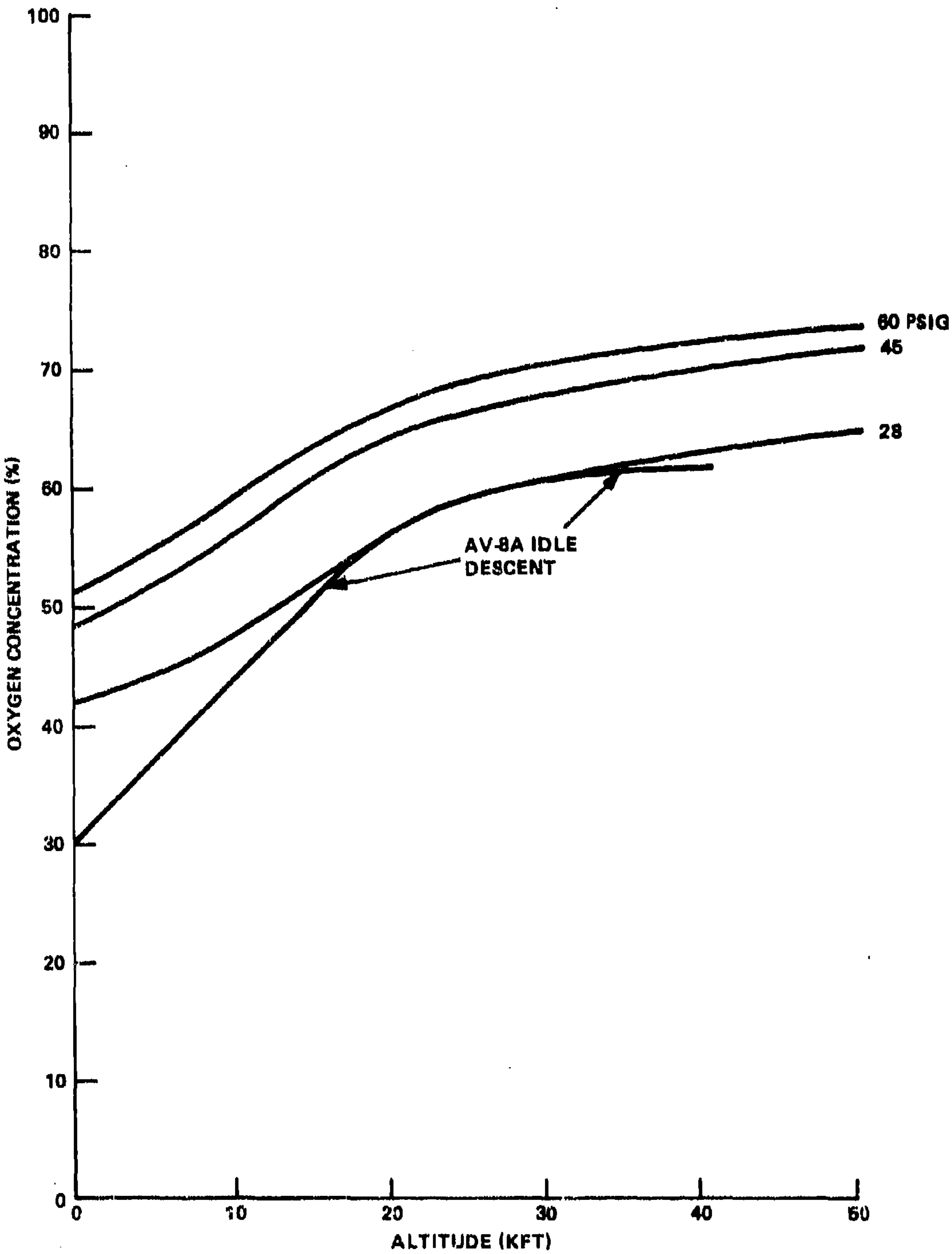


Figure 55 — Oxygen Concentration Vs. Altitude (50 lpm Outlet Flowrate)

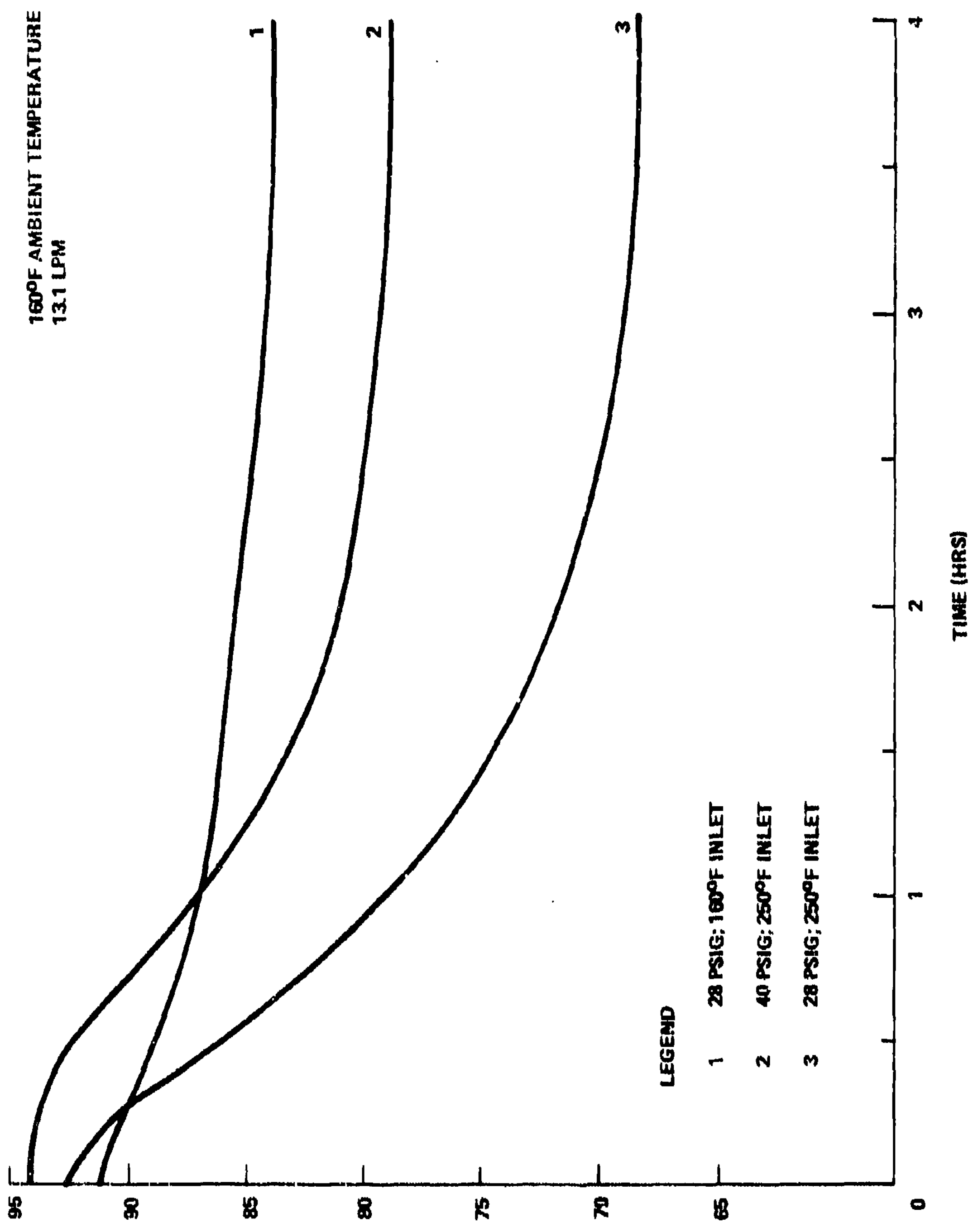


Figure 56 — Oxygen Concentration Vs. Time for High Temperature Inlet Air at Sea Level

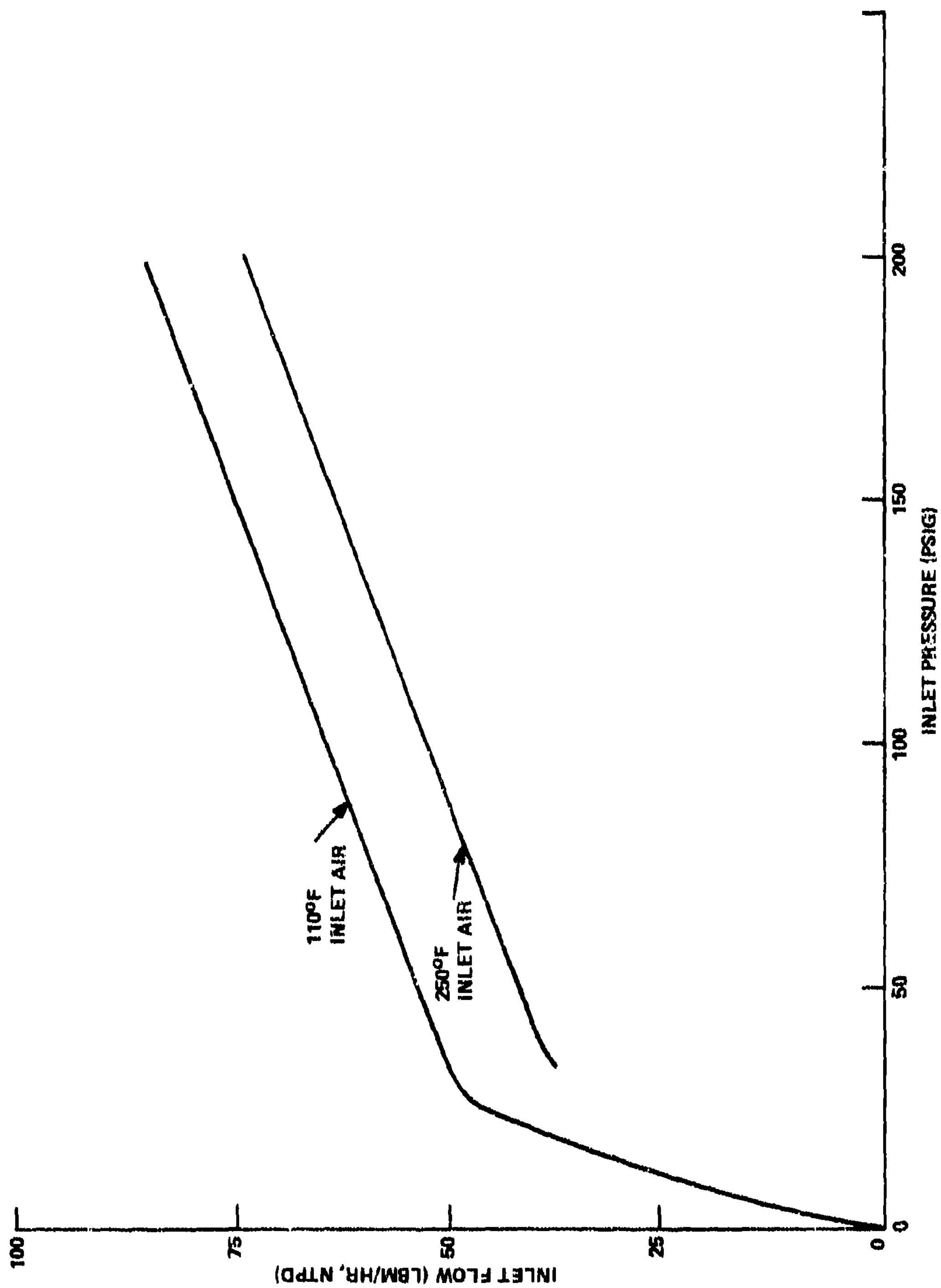


Figure 57 — Inlet Air Flowrate Vs. Inlet Pressure for High Temperature Inlet Air

in Table 6 and Figure 59. At the conclusion of the four hour periods, outlet flowrate was varied and the resulting concentrations recorded. Results are presented in Figure 59, which shows performance variation with standard ambient and inlet air temperatures.

It should be mentioned that all concentrators when initially delivered contained a cycle time of 12 seconds, i.e., nitrogen exhaust every 6 seconds and a control valve speed of 5 revolutions/minute. With the realization that initial AV-8A heat exchanger design showed high temperature inlet air throughout most of the operational envelope, a decision was made to employ the faster cycle time to improve performance (before the modification, oxygen concentration degradation with time with an inlet pressure of 40 psig was similar to the present with 28 psig).

The OEAS oxygen concentrator was tested in a typical mission profile with design maximum inlet air temperature, i.e., 250°F at sea level, 200°F at 10 and 20,000 feet, and 160°F at 30,000 feet or above. The test was initiated 5 minutes after the concentrator was soaked at an ambient temperature of 160°F for 48 hours. Test altitudes were held for 20 minutes each, with various outlet flowrates drawn and oxygen concentrations measured. All testing was conducted with an inlet pressure of 28 psig (referenced to the test altitude) at standard ambient temperature.

Results are presented in Table 7 which shows times at test points and for transition of altitude and inlet air temperature, variation of outlet flowrate and the resulting oxygen concentration. Temperatures of primary interest in high temperature evaluation are also presented. As presented in these results, oxygen purities delivered were all within acceptable limits, although concentrations delivered with an outlet flow of 13.1 lpm (NTP) were below those with lower flowrates at 40 and 50,000 feet. Preliminary flight tests results (reference 5) have indicated a maximum inlet air temperature (high speed, hot day low level flight) of approximately 175°F, indicating good heat exchanger performance. However, as presented in Table 7, concentrator performance is satisfactory with maximum design temperatures.

With the realization that time is the overriding factor with concentrator temperature evaluation, additional high inlet air temperature tests were conducted with set parameters for extended lengths of time. These tests were run at altitudes of 30,000 feet and above, where the need for a high purity breathing gas exists. A 24 point test matrix was conducted with variation of inlet air temperature, pressure and outlet flowrate.

Results of these tests, showing oxygen purity degradation with time, are presented in Figures 60, 61, and 62 for altitudes of 30,000, 40,000 and 50,000 feet respectively. The rates of concentration drop with time increased with inlet air temperature (160 vs. 250°F), inlet air pressure (28 vs. 60 psig), oxygen outlet flow (3 vs. 9 lpm (NTP)), and with increase in altitude. The relative performance at each altitude is presented in Figures 63 and 64.

These tests revealed the importance of pressure and/or temperature limitation at altitude. An additional 3 hour test at 30,000 feet with an inlet pressure of 90 psig and standard temperature (heaters activated) was successfully completed (no performance degradation). A high temperature altitude summary which describes test conditions and time, when degradation was initially observed, and the approximate time to warning activation (89 percent oxygen) is presented in Table 8.

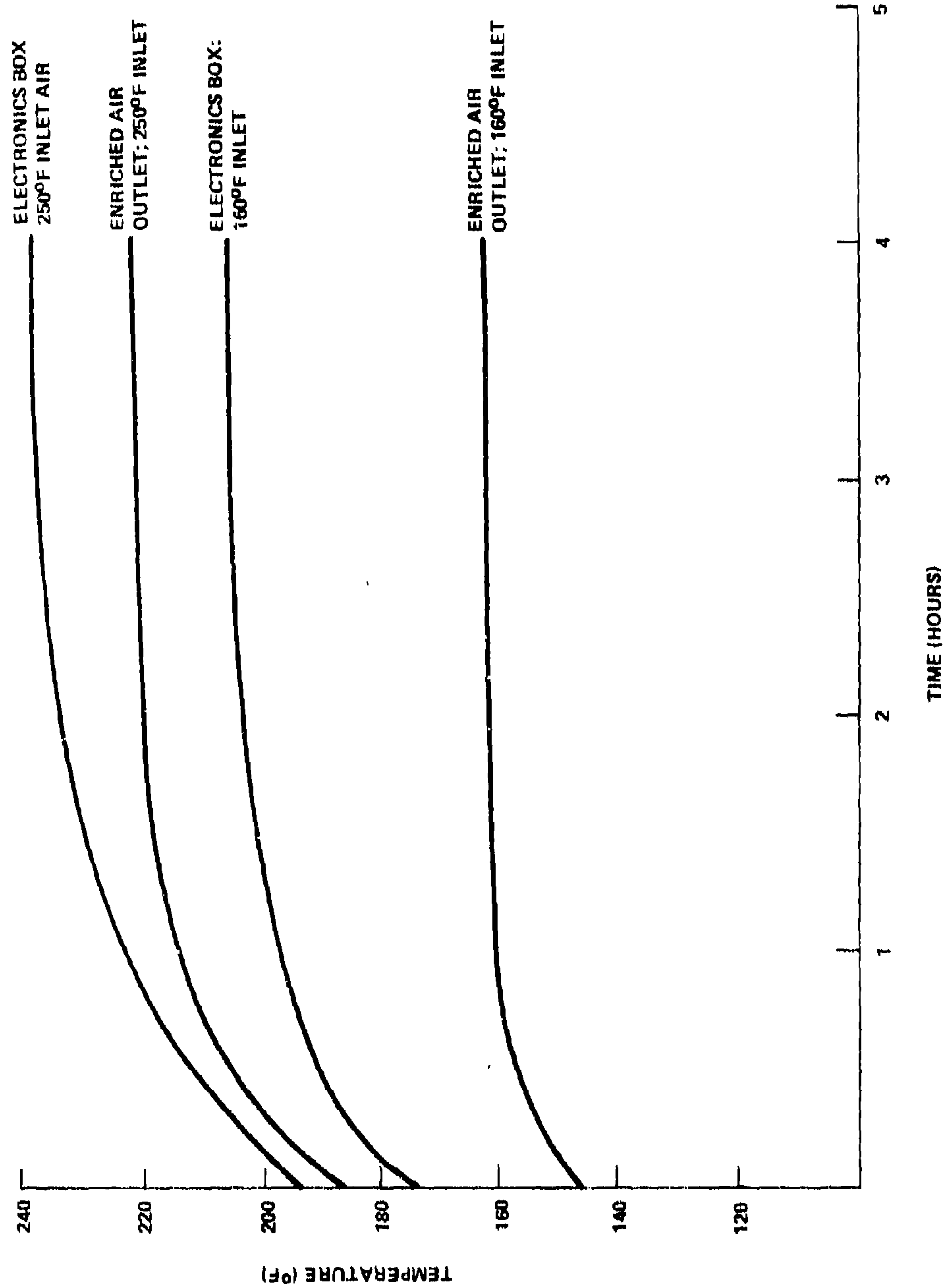


Figure 58 – Component Temperature Vs. Time for High Temperature Inlet Air

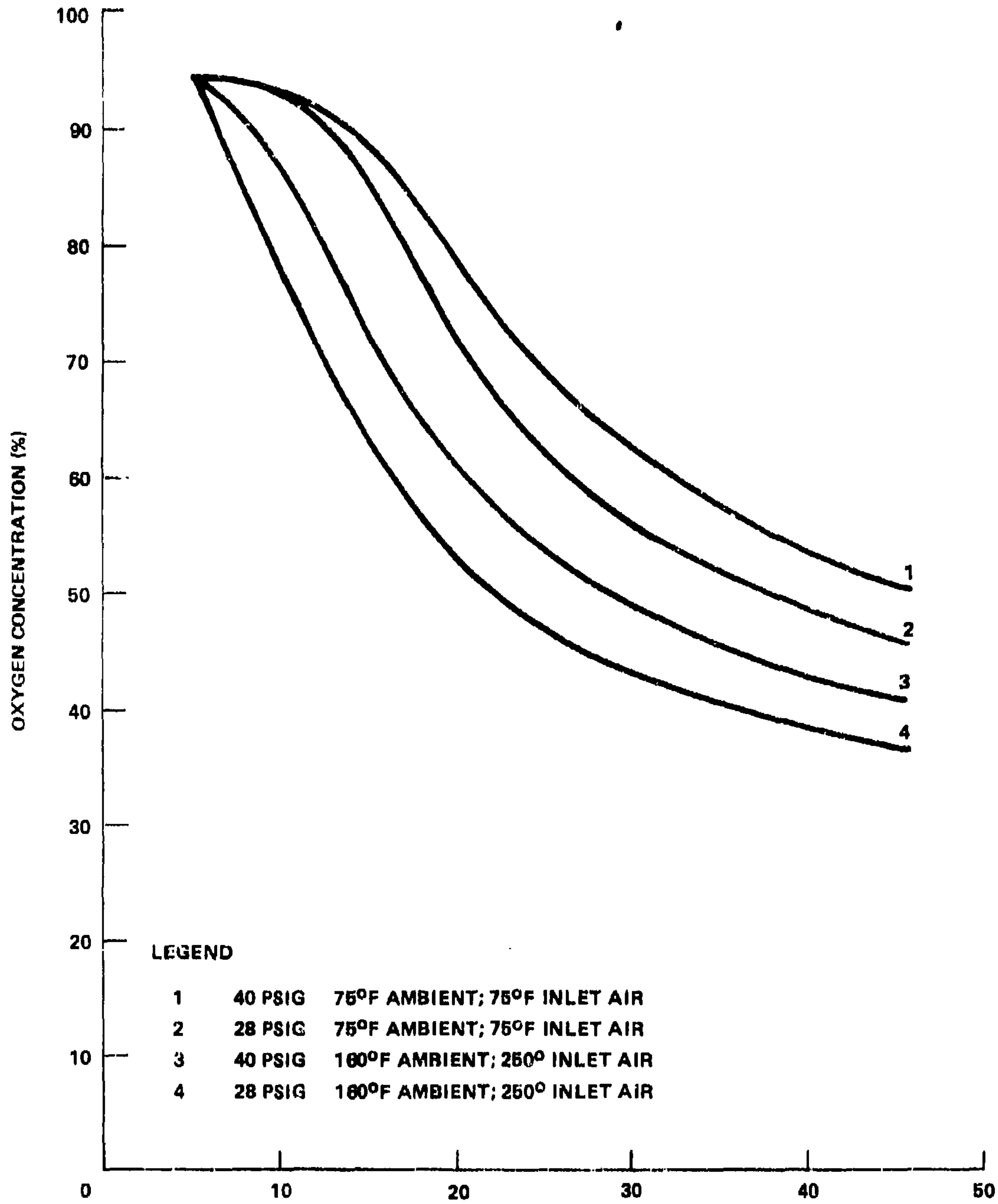


Figure 59 – Oxygen Concentration Vs. Inlet Air for High Temperature at Sea Level

Table 6

OEAS CONCENTRATOR COMPONENT TEMPERATURE FOR HIGH TEMPERATURE INLET AIR

Inlet Air Temp (°F)	Component (See Key)	Time (Minutes)						
		0	15	30	60	120	180	240
160	T_1	97	101	104	104	105	106	106
	T_2	150	159	160	160	162	162	162
	T_3	173	183	191	197	204	206	206
	T_4	146	153	158	160	162	162	162
250	T_1	107	113	115	117	120	121	121
	T_2	198	210	215	218	220	221	222
	T_3	194	203	212	223	234	237	238
	T_4	186	200	205	215	215	220	220

T_1 – Air Temperature; inlet to pressure reducer/control valve assembly; measured on surface of aluminum tubing midway between air filter and pressure reducer.

T_2 – Nitrogen enriched exhaust.

T_3 – Electronics box (external surface).

T_4 – Enriched air outlet (on surface of 5/16 inch OD tubing 6 feet from outlet port).

Table 7

HIGH TEMPERATURE/ALTITUDE MISSION PROFILE PERFORMANCE

Time (minutes)	Altitude (feet x 1000)	Inlet Air Temp (°F)	Outlet Flow (lpm)	Oxygen (%)	Temperature (°F) (see key)			
					T_1	T_2	T_3	T_4
0 to 12	0	75 to 200	13.1	88.1	–	–	–	–
12	0	200	13.1	88.1	163	149	154	92
18	0	230	13.1	88.1	188	166	158	101
24	0	250	13.1	88.1	200	178	163	107
30	0	250	13.1	87.0	204	183	167	110
39	0	250	13.1	86.0	206	189	171	111
39 to 49	0 to 10	250 to 200	13.1 to 9.6	–	–	–	–	–
49	10	200	9.6	94.4	182	176	179	105
63	10	200	9.6	94.4	177	171	182	104
69	10	200	9.6	94.4	178	171	184	105
69 to 74	10 to 20	200	9.6 to 7.7	–	–	–	–	–
75	20	200	7.7	94.6	178	169	185	105
87	20	200	7.7	94.6	178	169	186	105
95	20	200	7.7	94.6	178	169	187	105

Table 7 (Continued)

Time (minutes)	Altitude (feet x 1000)	Inlet Air Temp (°F)	Outlet Flow (lpm)	Oxygen (%)	Temperature (°F) (see key)			
					T_1	T_2	T_3	T_4
95 to 104	20 to 30	200 to 160	7.7 to 4.8	–	–	–	–	–
105	30	160	4.8	94.6	165	159	188	100
119	30	160	9.6	94.7	156	151	188	98
124	30	160	4.8	94.6	154	149	187	98
124 to 127	30 to 40	160	4.8 to 3.75	–	–	–	–	–
127	40	160	3.75	94.7	152	145	185	98
133	40	160	3.75	94.7	152	145	185	98
142	40	160	7.5	94.8	–	–	–	–
144	40	160	13.1	92.3	–	–	–	–
147	40	160	3.75	94.7	151	144	183	98
147 to 153	40 to 50	160	3.75 to 3.9	–	–	–	–	–
153	50	160	3.9	94.7	151	142	183	98
165	50	160	7.8	94.8	150	142	183	98
168	50	160	10	94.7	–	–	–	–
170	50	160	13.1	93.2	–	–	–	–
173	50	160	3.9	94.5	149	139	182	98

T_1 – Air Temperature; inlet to pressure reducer/control valve assembly; measured on surface of aluminum tubing midway between air filter and pressure reducer.

T_2 – Nitrogen enriched exhaust.

T_3 – Electronics box (external surface).

T_4 – Enriched air outlet (on surface of 5/16 o.d. tubing 6 feet from outlet port).

Low Temperature

The OEAS oxygen concentrator was low temperature tested through both variation of inlet air and ambient temperature. Performance degradation (drop in oxygen concentration) was found negligible with the unit operating initially at standard ambient temperature. With start up at standard inlet air and ambient temperature, the reduction of inlet air to 0°F and ambient temperature to -65°F produces insignificant degradation at sea level. This is due to adequate heater capacity for raising inlet air temperature, and through ambient warm up within the thermal shroud by solenoid and electronics module warm up air dissipation. Operation is seriously degraded (adsorption selectivity) without heating capability, evident during prototype laboratory evaluation (8).

Performance was further evaluated with start up after periods of non-operating 'cold soak'. These tests were conducted with the unit exposed to ambient temperatures of -40 and -65°F for four hour periods with no air or power applied. Start up was conducted with inlet pressures of 28 and 40 psig, and an inlet air temperature of -15°F. A bypass in the inlet air line was utilized in cooling the air prior to being supplied to the concentrator. Although the minimum design inlet air temperature was stated as 0°F, further cold day airframe analyses have shown that this temperature can drop to -15°F. The differential however, has no impact on performance due to adequate heater capacity. Breathing gas flowrate was maintained at 13.1 lpm for all tests.

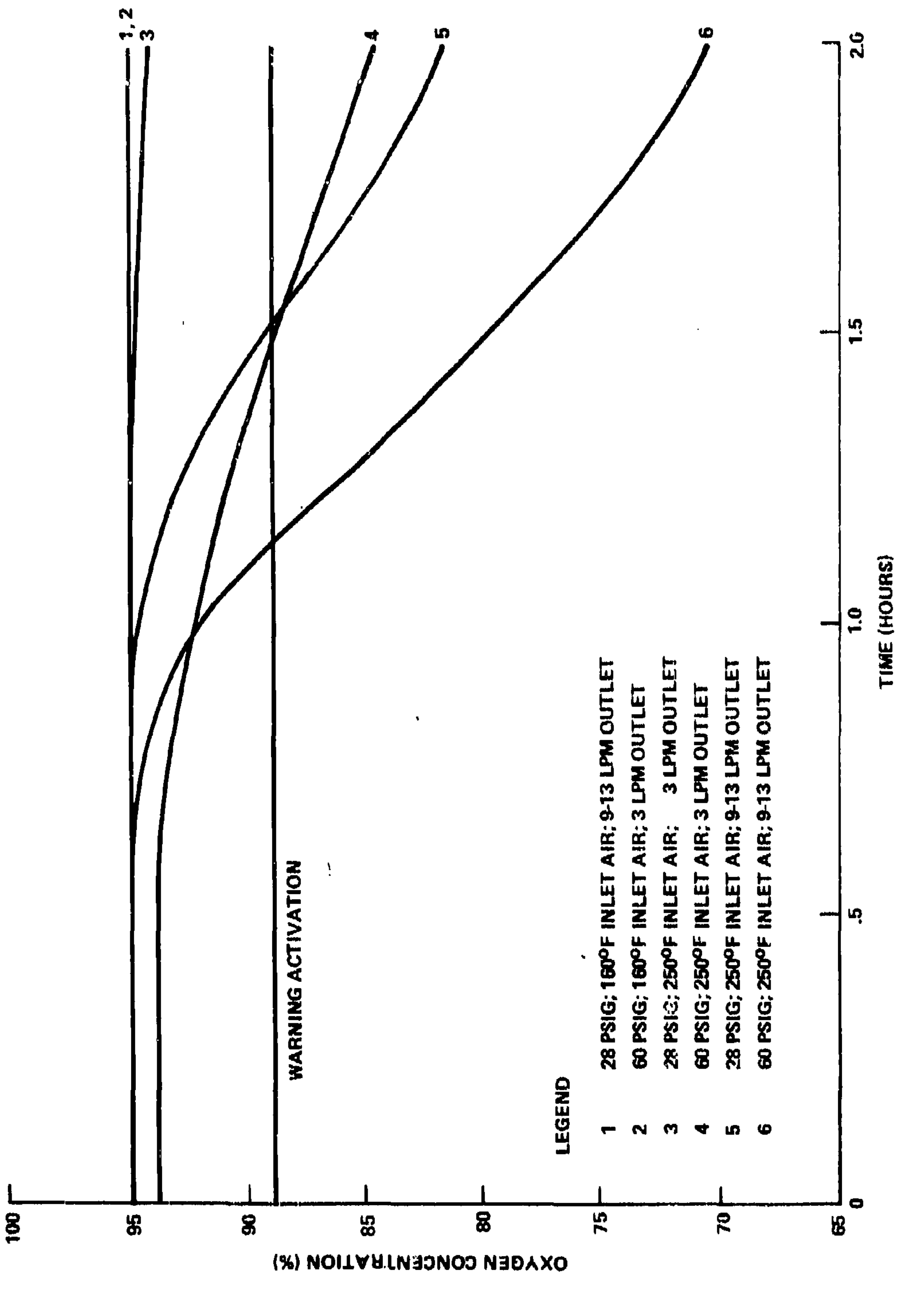
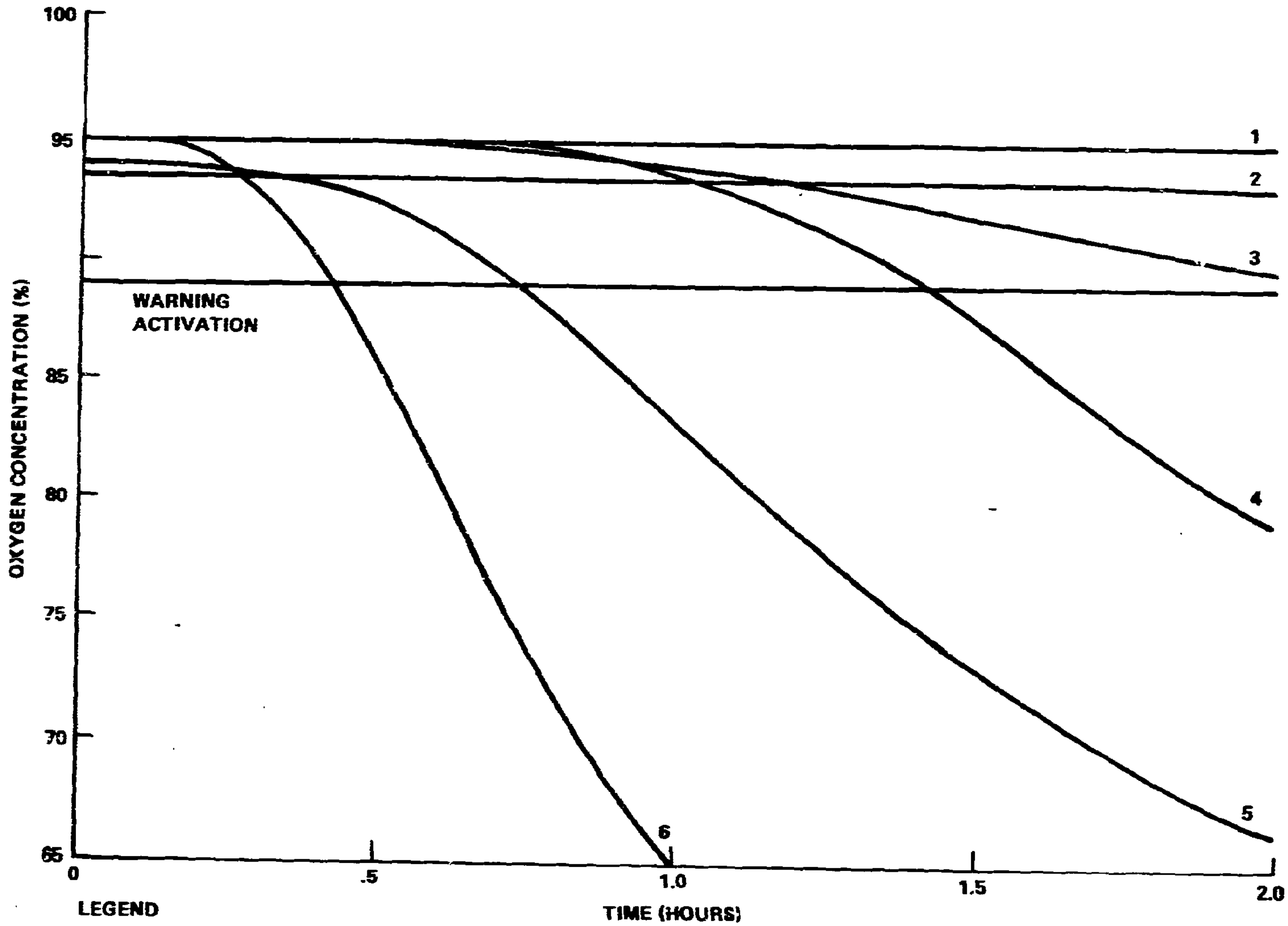


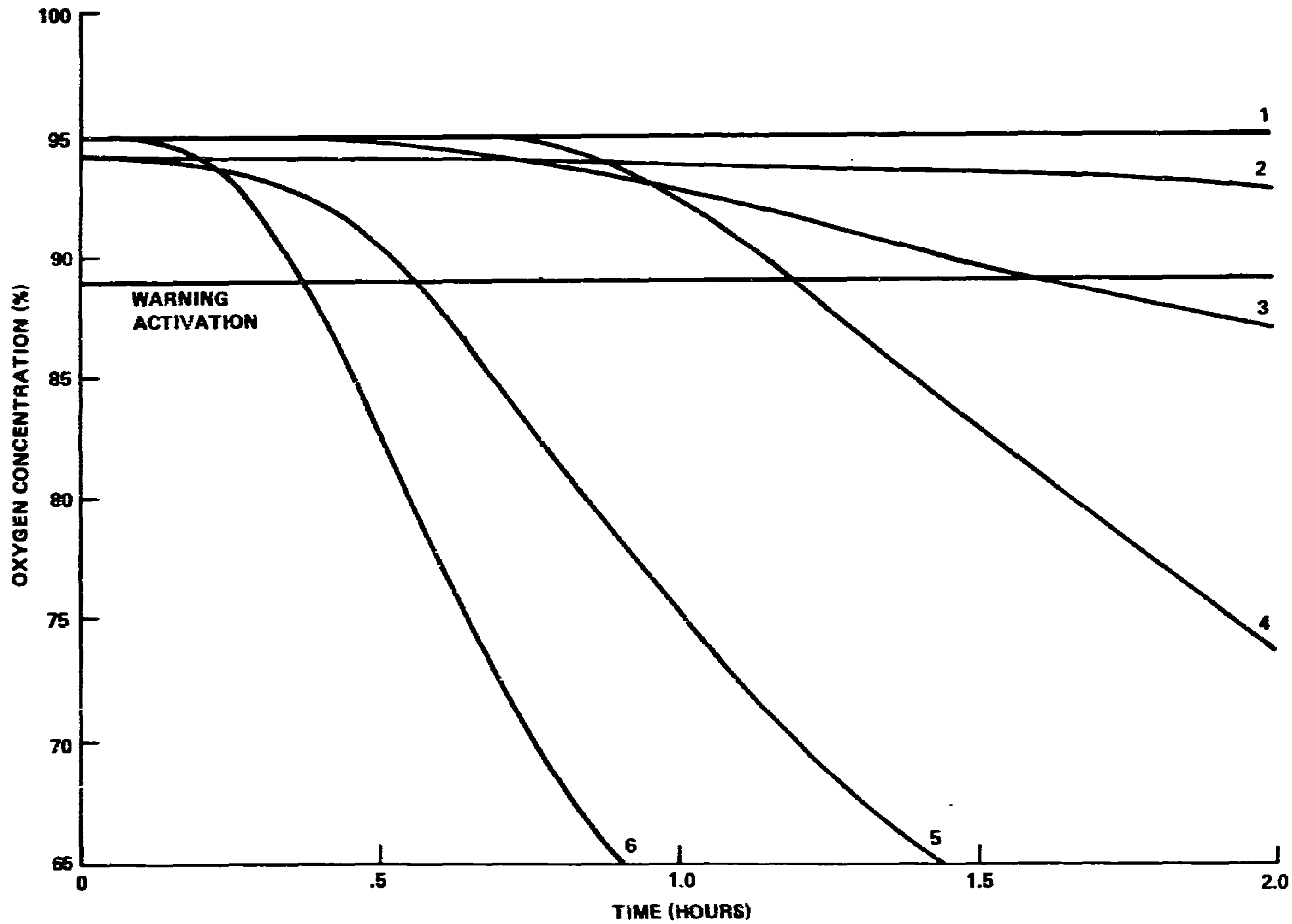
Figure 60 — Oxygen Concentration Vs. Time for High Temperature Inlet Air at 30,000 Feet



LEGEND

1	28 PSIG; 160°F INLET AIR; 9-13 LPM OUTLET	4	28 PSIG, 250°F INLET AIR; 9-13 LPM OUTLET
2	28 PSIG; 250°F INLET AIR; 3 LPM OUTLET	5	60 PSIG, 250°F INLET AIR; 3 LPM OUTLET
3	60 PSIG, 160°F INLET AIR; 9-13 LPM OUTLET	6	60 PSIG; 260°F INLET AIR; 9-13 LPM OUTLET

Figure 61 – Oxygen Concentration Vs. Time for High Temperature Inlet Air at 40,000 Feet



LEGEND

1	28 PSIG, 160°F INLET AIR; 9-13 LPM OUTLET	4	28 PSIG, 250°F INLET AIR; 9-13 LPM OUTLET
2	28 PSIG, 250°F INLET AIR; 3 LPM OUTLET	5	60 PSIG, 250°F INLET AIR; 3 LPM OUTLET
3	60 PSIG, 160°F INLET AIR; 9-13 LPM OUTLET	6	60 PSIG, 250°F INLET AIR; 9-13 LPM OUTLET

Figure 62 – Oxygen Concentration Vs. Time for High Temperature Inlet Air at 50,000 Feet

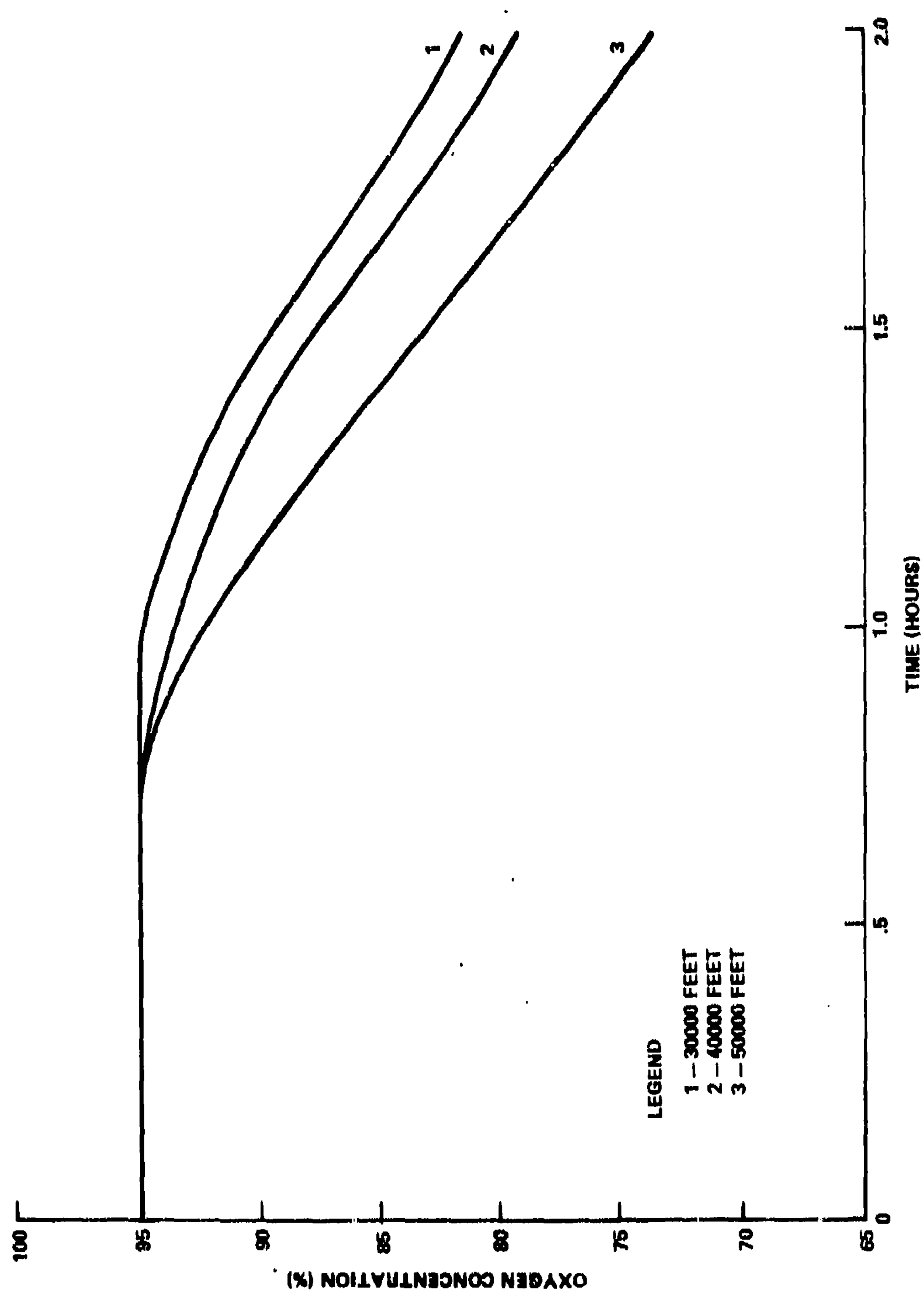


Figure 63 — Oxygen Concentration Vs. Time for 250°F Inlet Air (28 Psig)

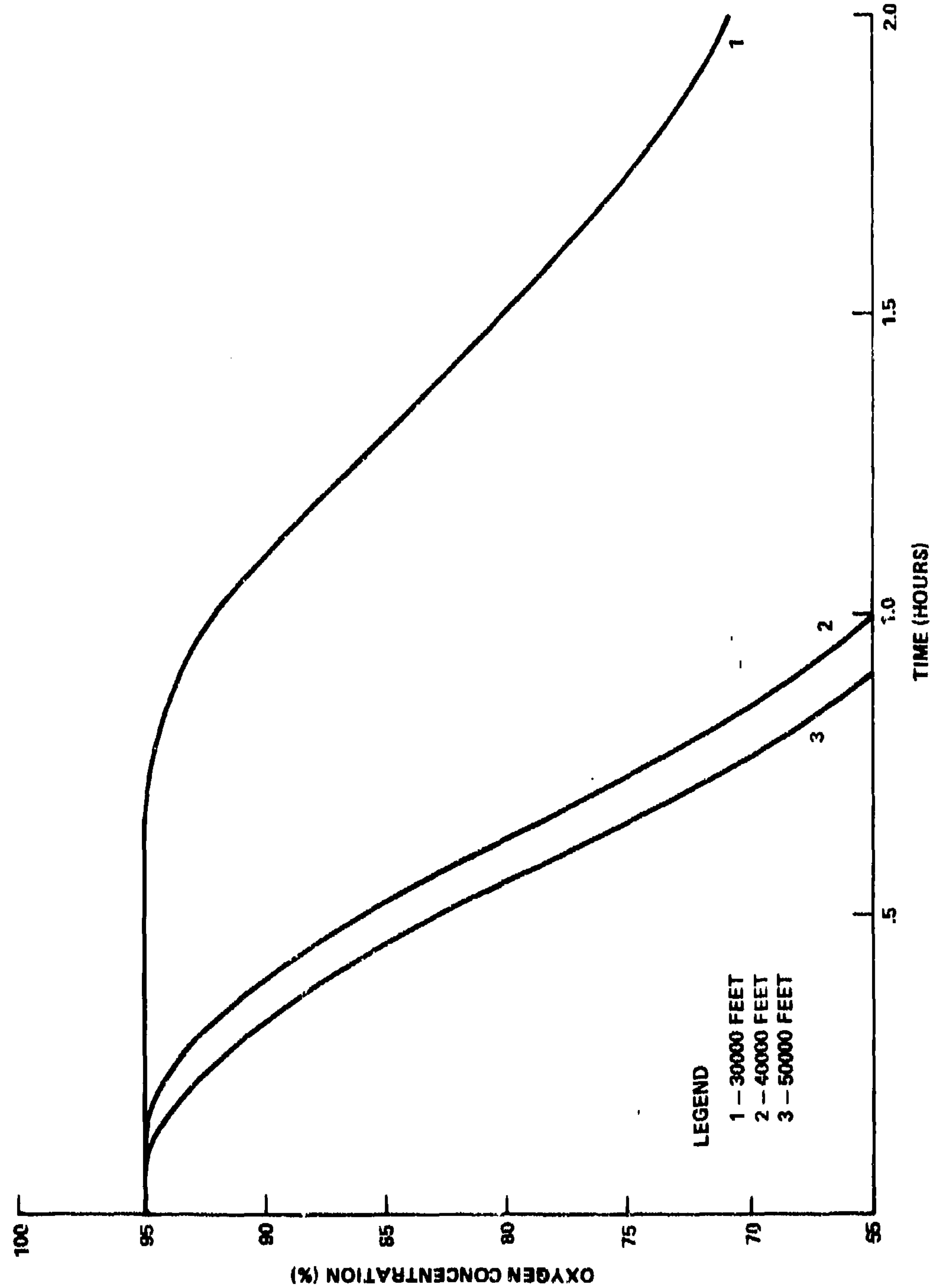


Figure 64 – Oxygen Concentration Vs. Time for 250°F Inlet Air (60 Psig)

Table 8

HIGH TEMPERATURE INLET AIR/ALTITUDE PERFORMANCE SUMMARY

Altitude (Feet)	Inlet Air Pressure (psig)	Inlet Air Temperature (°F)	Outlet Flow (lpm)	Test Time (HRS)	Start in Performance Decline (HRS)	Est. Time To Warning (HRS)	Drop in Concentration at Test Conclusion (%)
30,000	28	160	9.0-13.1	3.0	None	N/A	None
30,000	28	250	3.0	2.0	None	N/A	None
30,000	28	250	9.0-13.1	2.0	1.00	1.50	13.3
30,000	60	160	9.0-13	3.0	1.00	>3.0	1.0
30,000	60	250	3.0	2.0	0.55	1.50	9.4
30,000	60	250	9.0-13.1	2.0	0.67	1.20	24.4
40,000	28	160	9.0-13.1	3.0	None	N/A	None
40,000	28	250	3.0	2.0	1.40	>2.0	0.4
40,000	28	250	9.0-13.1	2.0	0.75	1.40	15.7
40,000	60	160	9.0-13.1	3.0	0.52	2.20	8.4
40,000	60	250	3.0	2.0	0.17	0.75	27.9
40,000	60	250	9.0-13.1	1.0	0.15	0.45	30.0
50,000	28	160	9.0-13.1	2.0	None	N/A	None
50,000	28	250	3.0	2.0	0.75	>2.0	0.5
50,000	28	250	9.0-13.1	2.0	0.73	1.20	21.4
50,000	60	160	9.0-13.1	3.0	0.33	1.50	11.1
50,000	60	250	3.0	1.5	0.15	0.60	30.2
50,000	60	250	9.0-13.1	1.0	0.12	0.40	33.3

Results are presented in Figures 65 and 66 for -65 and -40°F, respectively. The rates at which concentration increases are improved with an increase in pressure, and inlet or ambient temperature. Cycle time again affected performance, with 12 second units (5 rpm) found to perform better with time (maximum concentration was achieved approximately one hour with 40 psig inlet pressure at an ambient temperature of -65°F). Minimum acceptable oxygen concentration after stabilization at minimum temperature, then ascending to 30,000 feet or above has been determined to be 93 percent for breathing gas flowrates of 5-10 lpm.

Although the concentrator provides ample purity to extinguish the warning light at sea level on start up, of particular concern is the ability of the concentrator to perform with ascent in altitude after cold soak without allowing warm up for extended periods of time. The concentrator was cold soaked at an ambient temperature of -40°F for a 12 hour period. Start up was initiated with inlet air at -15°F at 28 psig, with an outlet flow of 13.1 lpm. After approximately 5 minutes of sea level operation, chamber altitude was raised to 25,000 feet, with the resulting oxygen concentration measured. An inlet air temperature at -15°F and flowrate of approximately 8 lpm were maintained throughout the altitude portion of testing. The inlet pressure of 28 psig was referenced to the altitudes specified.

Results are presented in Figure 67 for oxygen concentration and altitude versus test time. The effect of cold soak time was evident with an identical test conducted with a soak time of 4 hours at -40°F, where concentrations in excess of 90 percent oxygen were measured upon attaining 25,000 feet.

Bleed Air Contamination

Throughout the test and evaluation program, the oxygen concentrator was subjected to "ideal" conditions with respect to inlet air, i.e., first passed through coalescing filters and dryer. Preliminary analysis prior to Prowler flight testing was accomplished with reference 27, which assumed engine bleed air contamination with maximum levels as follows (reference 9).

Substance	Parts per Million
Carbon dioxide	5000.0
Carbon monoxide	50.0
Ethanol	1000.0
Fluorine (as HF)	0.1
Hydrogen peroxide	1.0
Aviation fuels	250.0
Methyl alcohol	200.0
Methyl bromide	20.0
Nitrogen oxides	5.0
Acrolein	0.1
Oil breakdown products (e.g., aldehydes)	1.0
Ozone	0.1

The resulting flight test experience (2) showed that the only trace constituents found in the oxygen product (with or without a bleed air hydrocarbon filter) were oxygen cleaning compound, carbon dioxide and moisture. The maximum level of carbon dioxide measured in any sample was 3.0 ppm, less than the 10 ppm specified as the maximum concentration allowable in MIL-0-27210E (12).

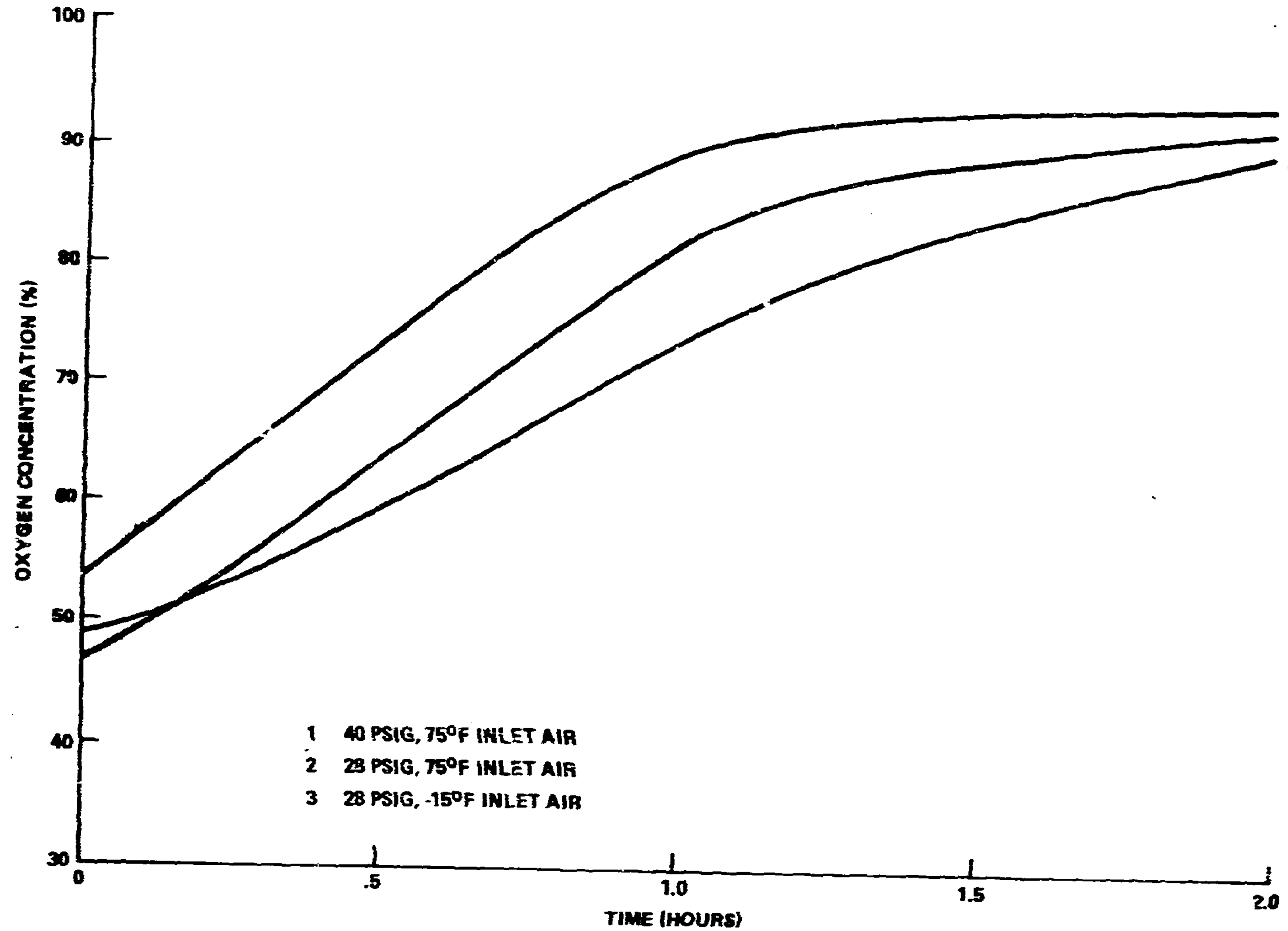


Figure 65 – Oxygen Concentration Vs. Time After 4 Hour Cold Soak at -65°F

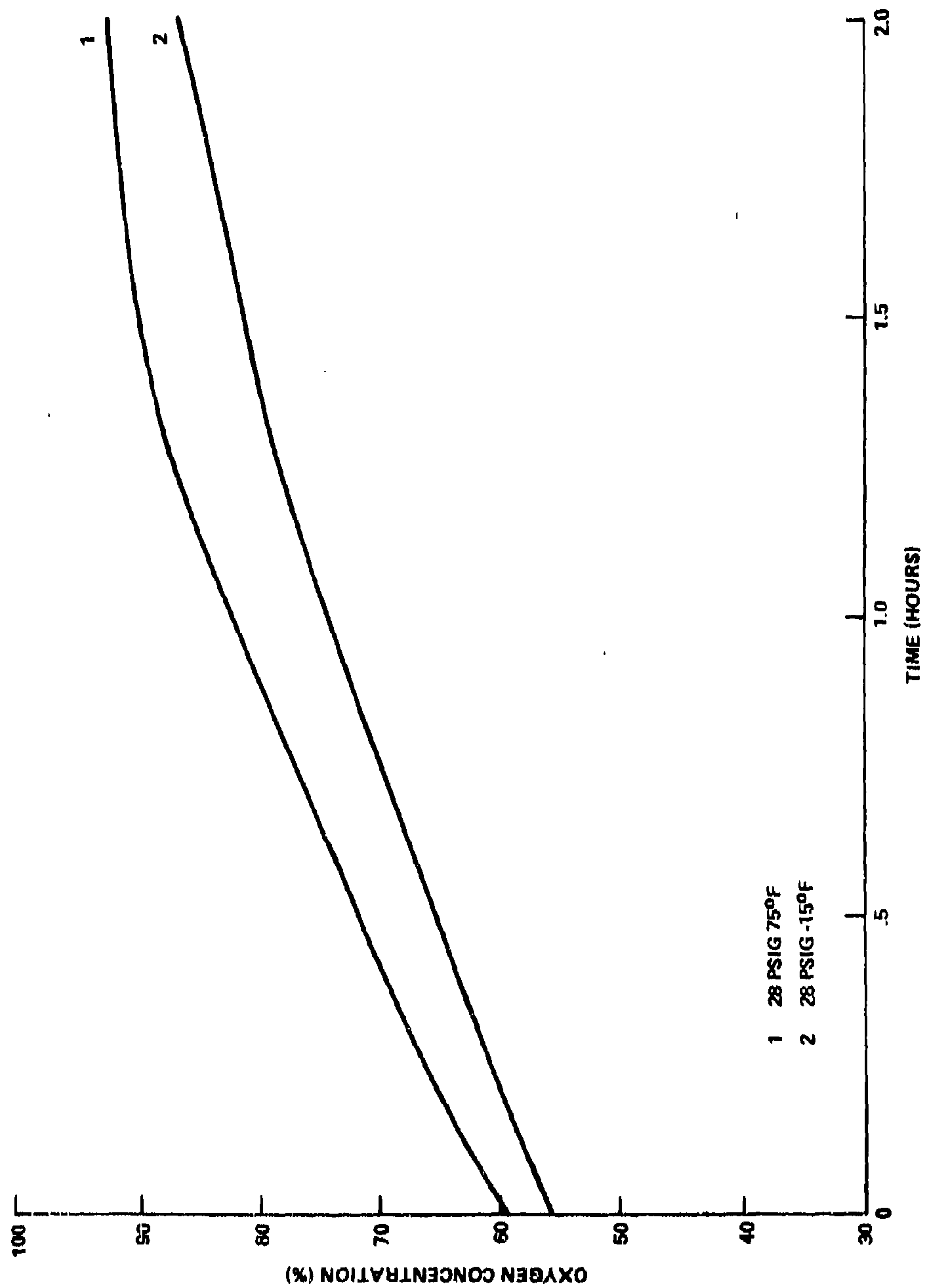


Figure 66 — Oxygen Concentration Vs. Time After 4 Hour Cold Soak at -40°F

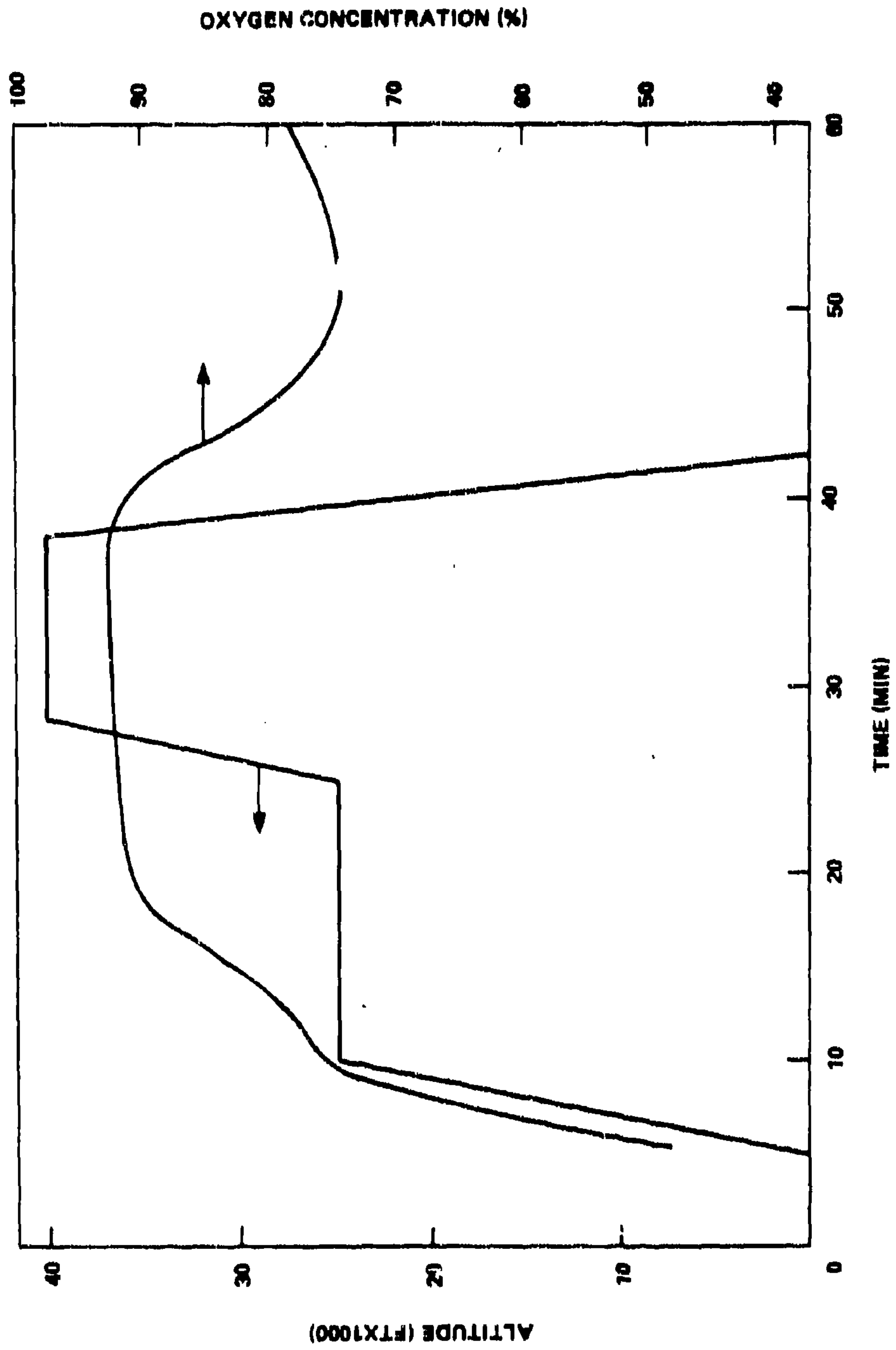


Figure 67 — Oxygen Concentration and Altitude Vs. Time After Cold Soak at –40°F Ambient

Continued analysis of the ability of the concentrator to filter contaminants were made by the U.S. Air Force School of Aerospace Medicine on an OEAS concentrator identical, with the exception of some structural modifications, to that employed in all other testing described herein. The results (6) showed adequate filtering of the contaminants methane, ethane, hexane and methanol.

The entrance of particulate matter to the concentrator is also of concern when entrained in the filter cartridge. the accumulation of particles will result in an excessive pressure drop across the filter (decrease in bed inlet pressure) and a drop in oxygen concentration. This phenomenon was experienced during the NAVAIRDEVCEN program, when the need for a particulate filter at the outlet of the air dryer was evident. Only through operational experience with extended aircraft installed hours will the frequency of filter cartridge change be determined and analysis made on the spent cartridges to determine the rate at which the aircraft engine will generate submicron particles.

Temperature Shock

The oxygen concentrator was temperature shock tested in accordance with MIL-STD-810C, Method 503.1, Procedure I. The unit was not operating during this test, and all ambient ports were capped. The following test schedule was employed:

Temperature (°F/°C)	Exposure Time (Hrs)
160/71	4
-70/-57	4
160/71	4
-70/-57	4
160/71	4
-70/-57	4

The unit was transferred within one minute to a cold (or hot) chamber at the conclusion of each four hour exposure. The concentrator was allowed to stabilize at room temperature after the 24 hour period and checked for operation. Performance was found normal with no deviation in power consumption or cycle time, and showed no structural crack or deformation.

Humidity

The oxygen concentrator was humidity tested in accordance with MIL-STD-810C, Method 507.1, Procedure II. The unit was not operating during this test and all ambient ports were capped. The concentrator was first dried at 129°F (54°C) for 24 hours, then conditioned at 73°F (23°C) and 50 ± 10 percent relative humidity for 24 hours. After adjustment of ambient temperature to 86°F (30°C) and relative humidity to 94 ± 4 percent, ambient temperature was varied according to Figure 68. Five continuous cycles were employed, with relative humidity maintained at 94 ± 4 percent throughout the 240 hour period. Conditioning at 86°F and 50 ± 10 percent relative humidity was then repeated. The unit was then checked within one hour of test completion for operation, showing normal performance with respect to power consumption and cycle time, and showed no structural deformation or deterioration, although the pressure reducer and thermal control system solenoid showed slight evidence of corrosion.

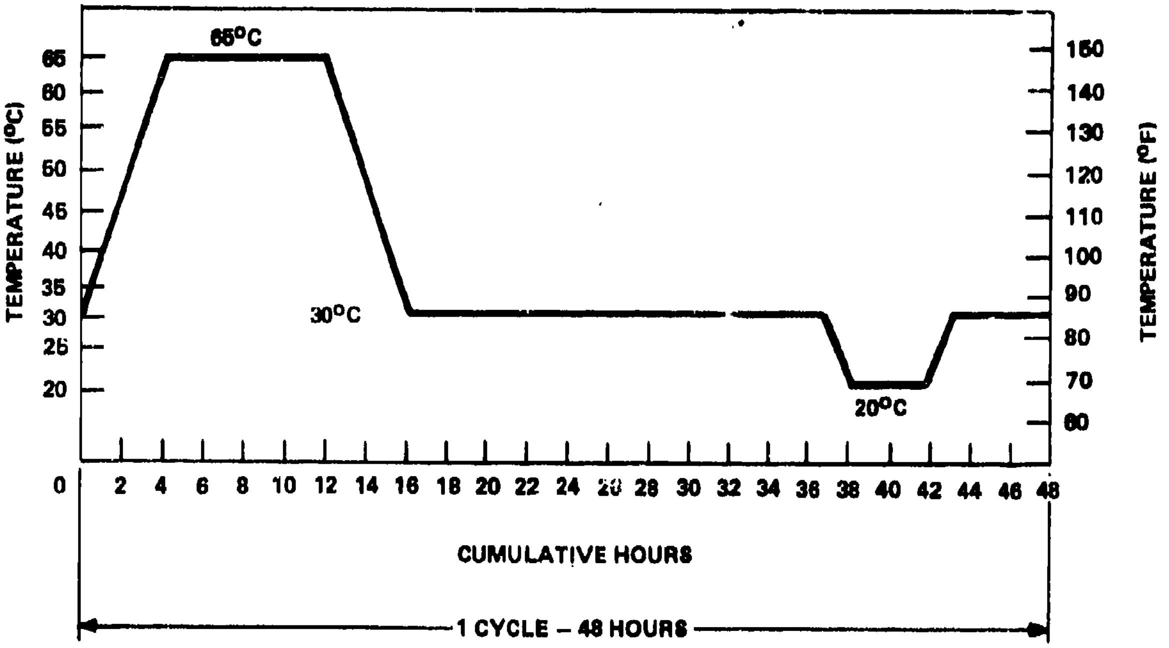


Figure 68 – OEAS Concentrator Humidity Cycle (Procedure – II)

Temperature-Humidity-Altitude

The oxygen concentrator was temperature-humidity-altitude tested in accordance with MIL-STD-810C, Method 518.1, Procedure I. The unit was not operating during this test and again, all ambient ports were capped. Four continuous cycles, as depicted in Figure 69, were employed for variation of ambient conditions. After the 96-hour exposure and return to standard ambient conditions, the unit was subjected to 2.5 hours at -65°F ambient temperature at 50,000 feet, then returned to standard ambient conditions without humidity (first 5 hours of Figure 69).

Initial post test operational checks after stabilization at standard conditions were unsuccessful, with no motor current draw when supplied with 28 VDC. The third attempt at start up was successful, with normal cycling, heater activation and power consumption. However, subsequent attempts of operation resulted in failure for motor start. Electronics box disassembly revealed a broken lead/diode connection in the motor circuit within the epoxy/RTV contained in the box. It was theorized that the ambient temperature differential and not humidity caused the failure, resulting in varying expansion rates at the epoxy/RTV interface, and the disconnection caused by inadequate stress relief.

Vibration

Random vibration was accomplished under the guidelines of MIL-STD-810C (17) and McDonnell Douglas Report MDC A3780 (1). All testing was conducted on three units: S/N 806004E, of the ten purchased under contract 0128; S/N E1, Bendix development unit manufactured for Bendix in-house testing and S/N E2, Bendix development unit. Due to the long duration of this phase of the program (6 months) and as an aid in revealing how the concentrator evolved to its present configuration, each qualification attempt and its result is presented.

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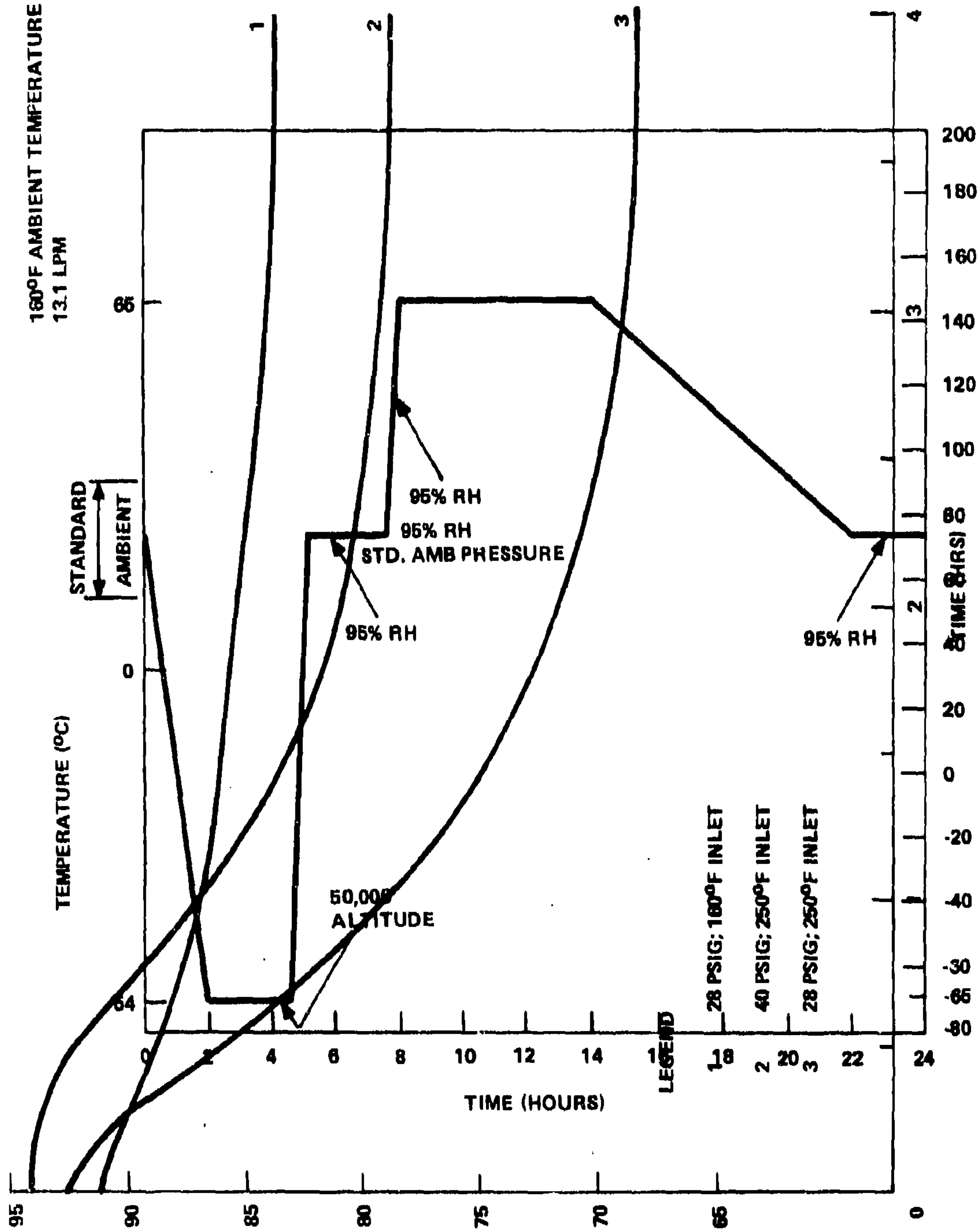


Figure 56 – Oxygen Concentration Vs. Time for High Temperature Inlet Air at Sea Level

Figure 69 – OAES Concentrator Temperature/Humidity/Altitude Cycle (Procedure I)

Early vibration tests conducted at Bendix were limited due to low capacity vibration equipment used (maximum 18 Grms vertical, 14 Grms horizontal, in accordance with Figure 514.2-2A of MIL-STD-810C), but provided a determination of the need for initial structural modifications. These included (1) the addition of a stabilizing plate on top of the unit which, due to the modular design of the system, showed a tendency of the beds, plenum, etc. to bump into each other during vibration and (2) a more rugged motor/gear assembly through motor mount extension.

Government testing was initiated on S/N 805004E in accordance with MIL-STD-810C, Category 5.2, Procedure IA. The power spectral densities, variable frequencies, and overall Grms was as follows, based on use for 2000 missions and a q value of 1200 psf:

	Functional Test	3 hr Endurance Test
G^2/Hz (PSD)	0.2016	0.778
f var (Hz)	89.19	32.38
G rms (G)	16.4	32.16

Each of these vibration envelopes is presented in Figure 70. The functional level shown is based on a test time of one hour in each axis.

The concentrator was operating for one hour (25 psig inlet, 13.1 lpm outlet) in the longitudinal (x) axis while being subjected to 16.4 Grms. Operation during this test showed abnormal heater activation, as both drew a constant 4-6 amps. This resulted in a high (150°F) nitrogen exhaust temperature (105-110 normal). Oxygen concentration, however, held constant throughout the one hour period.

The unit was then subjected to endurance (non-operating) level testing at 29.5 Grms (6 hour test level) and stopped after the first of six hours intended. An operational check revealed a break in the oxygen supply line (from plenum to outlet port). A visual check on the baseplate of the unit showed a dethreading of the spanner nut which holds the plenum to the baseplate and backing out of virtually all screws holding the modules (beds, electronics box, etc.) to the baseplate. Continued vibration could have resulted in their separation from the unit. This testing resulted in improved methods for locking of screws to modules and a change to stainless steel (from aluminum) in the oxygen supply line.

Testing was continued after repair in accordance with MIL-STD-810C and Figure 70. The intended test schedule was as follows:

Test	Axis	Time (hr)	Level
Functional	Longitudinal	1/2	16.4
Endurance	(Front to back)	3	23.2
Functional	(Front to back)	1/2	16.4
Functional	Lateral	1/2	16.4
Endurance	(Side to side)	3	32.2
Functional	(Side to side)	1/2	16.4
Functional	Vertical	1/2	16.4
Endurance	Vertical	3	32.2
Functional	Vertical	1/2	16.4

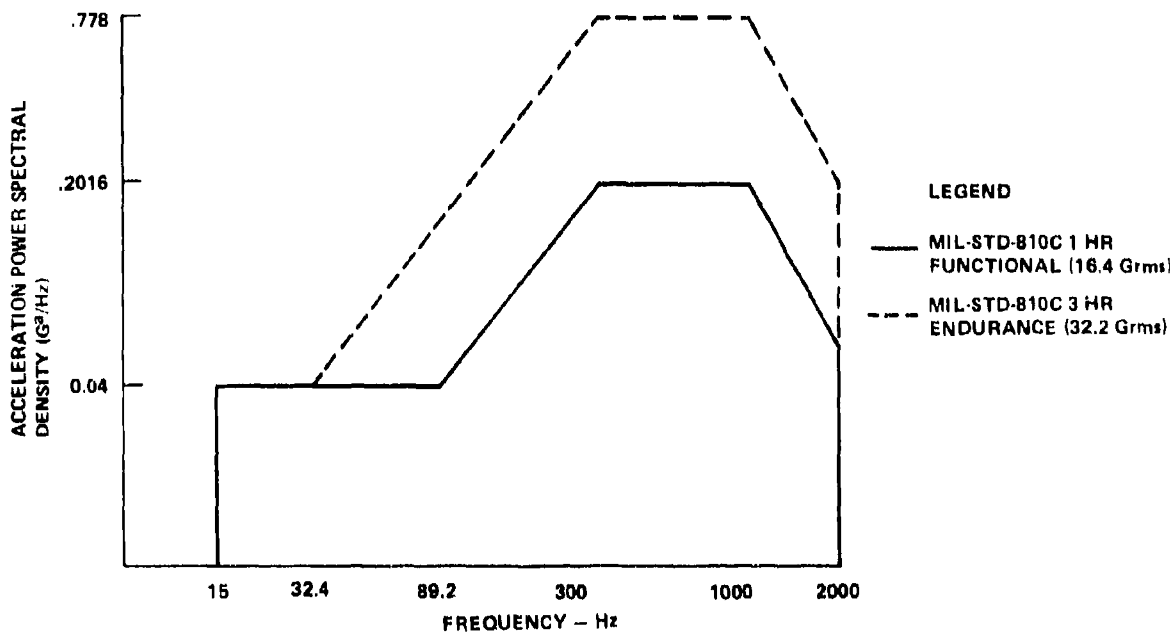
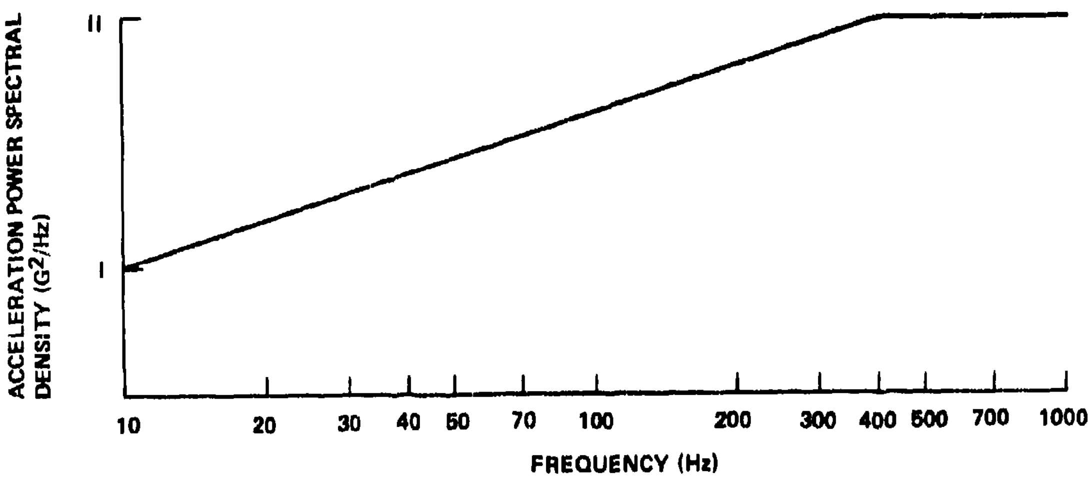


Figure 70 – MIL-STD-810C Random Vibration Envelopes

A motor stop (which results in no cycling and air as the effluent gas) was evident after the first fifteen minutes of functional testing in the longitudinal (x) axis. A voltage check on the electronics module terminal strip indicated an electronics failure. The remaining functional level testing was completed (unit unoperational) and one hour of endurance (32.2 Grms) was run for structural testing.

A retest after repair (same vibration envelope) was successful through the first half hour in the longitudinal axis. Testing was stopped after exposure to one hour of endurance level testing. A functional check showed the unit would not operate (no cycling). All endurance level testing (3 hrs/axis) was completed in order to learn more about the structural integrity of the unit as it had never before been subjected to high level testing for any extended period. Post test visual checks revealed a sound structure with no cracks in modules, screw loosening, etc. The electronics module remained the source of system failure, with broken leads, broken components, and their separation from the electronics board. Testing was started in the vertical (Z) axis on a backup system, S/N E1, to determine its ability to operate after subjected to high level endurance. Operation was normal throughout one half hour of functional level testing, while a check after one half hour of endurance level testing also showed normal operation. After one hour of endurance, however, the unit would not operate (cycle). Once again, failure in the electronics module was evident. Retests conducted at Bendix on the electronics box alone determined the need for addition of both hard epoxy and soft RTV throughout the electronics module.

Retests were attempted in order to qualify the system for the AV-8A Harrier, utilizing the random vibration envelope provided by MCAIR Report No. MDC A3780. This envelope (Figures 71 and 72) deviates from that found in MIL-STD-810C with respect to bandwidth, spectral density



SCHEDULE	I	II	Grms
FUNCTIONAL (VSTOL)	.01	.5	19.9
		(.75 VERT)	24.2
FUNCTIONAL (CRUISE)	.0005	.07	7.35
ENDURANCE (CRUISE)	.01	.5	19.9
		(.75 VERT)	24.2

Figure 71 – MDC A3780 Random Vibration Envelopes

and overall Grms. Based on this information provided, the test schedule for qualification of the concentrator for the AV-8A with use for 2000 missions is as follows:

Test	Axis	Time	Grms
Functional (Performance, Cruise)	Longitudinal (Front to Back)	25 min	7.3
Functional (Performance, VSTOL)	Longitudinal (Front to Back)	5 min	19.9
Endurance (Cruise)	Longitudinal (Front to Back)	6 hrs	19.9
Functional (Performance, Cruise)	Lateral (Side to Side)	25 min	7.3
Functional (Performance, VSTOL)	Lateral (Side to Side)	5 min	19.9
Endurance (Cruise)	Lateral (Side to Side)	6 hrs	19.9
Functional (Performance, Cruise)	Vertical	25 min	7.3
Functional (Performance, VSTOL)	Vertical	5 min	24.2
Endurance (Cruise)	Vertical	6 hrs	24.2

The functional tests in the longitudinal and lateral axes (Figure 73) showed no deviation with respect to oxygen concentration (93 percent) power consumption or heater activation. Post endurance checks also showed normal operation, while visual checks verified the structural integrity of the unit. Functional testing in the vertical directional at 24.2 Grms level showed two deviations from normal operation: (1) heater 1 remained on almost continuously throught the 5 minute period and (2) outlet pressure dropped 1 psig (23 in lieu of 24 psig).

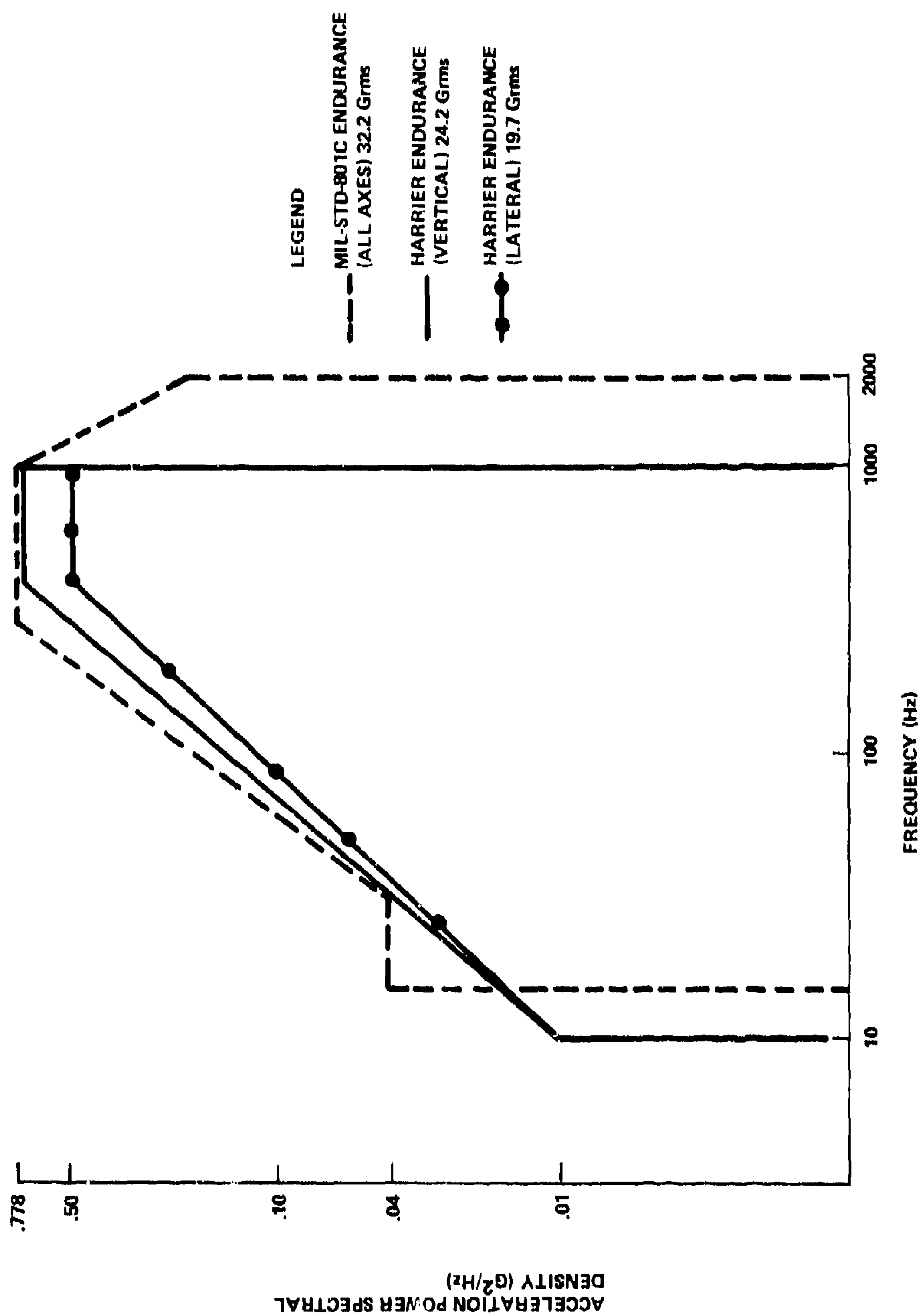


Figure 72 — Endurance Level Vibration Comparison

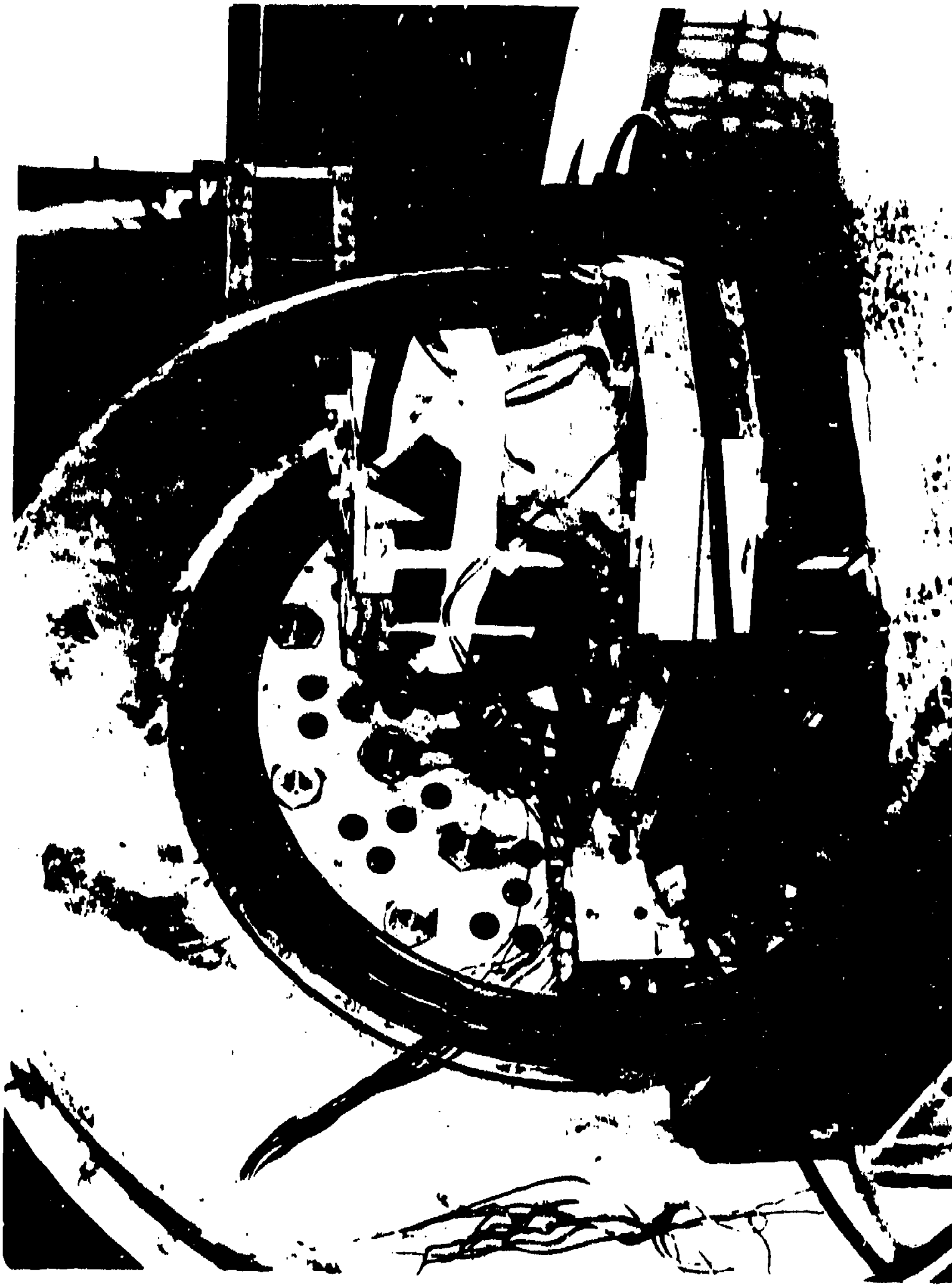


Figure 73 – OEAS Concentrator Mounted for Lateral Axis Vibration

Vibration testing was stopped after one hour of endurance at 24.2 Grms to check unit operation. Power consumption was normal although the supplying of pressurized air showed that the unit was not cycling (no exhaust heard, with air as the effluent gas). A check of voltage on the terminal strip of the electronics module again showed that the motor (and therefore the control valve) was not turning. An additional 2 hours of endurance testing was run in order to obtain additional information regarding structural integrity.

Analysis and rework at Bendix determined the cause of failure to be broken capacitors within the electronics module, which precluded power supply to the motor. Four aluminum capacitors were replaced with smaller tantalum capacitors with a higher vibration rating. An additional post was added to the center of the electronics module and all lightening holes were removed from the baseplate as aids in providing a more rigid structure.

Retest of S/N E1 to the McDonnell specification was begun in the vertical (Z) axis, as it was the higher level vibration in this attitude which had previously caused failure. Operation was normal throughout the functional test, and a check after one hour of endurance showed normal operation. Normal cycling was evident after two hours of endurance although oxygen concentration had dropped from 92 to 89 percent. The OEAS did cycle normally after three hours of endurance, but a large air leak was evident under the stabilization plate resulting in a drop in oxygen concentration to 35 percent. Removal of the plate revealed a crack in the aluminum tube joining the left bed outlet to the plenum (Figure 74). Testing was repeated (Z axis) on reserve unit S/N E2, which had never before been subjected to vibration but contained all modifications present on S/N E1. Cycling continued throughout functional level testing, although oxygen concentration dropped to 89 percent and showed a concentration of 84 percent when checked after one hour of endurance. A check on the stabilization plate area revealed a small air leak. A large leak was evident after the second hour of endurance, with an outlet concentration of 50 percent. At this time, abnormal heater operation was also evident, as heater 1 would remain in the off condition for five seconds (16-17 normal). Endurance level testing was completed fro 3 hours in the X and Y axis. The OEAS showed the ability to cycle after each of these runs while the leak, low concentration and abnormal heater operation were still present.

Testing was stopped to examine the unit, as it was believed the same aluminum tube failure was present. Removal of the stabilization plate revealed a crack in the copper tube which joins the rotary valve to the left bed (Figure 74). Further inspection revealed that two screw clamps which grasp the motor/valve housing were loosened. It was theorized they were not tightened during assembly (they were not checked prior to vibration testing) and allowed vertical movement of the entire motor assembly, causing the tube crack. The copper tubing was removed from S/N E1 and installed on E2 to confirm (1) that the clamps had not shaken loose during vibration in the vertical axis and (2) abnormal heater operation was caused passing by passing of leakage air across the filter housing (which contains the termistor).

Functional plus 3 hours of endurance level testing was accomplished on the repaired S/N E2 in the X and Y axes. The OEAS was able to cycle normally during functional tests and when post endurance checks were made. Heater operation (on/off cycling) also resumed normally, confirming concern (2) above. Three hours of endurance in the vertical axis showed no loosening of screw clamps, while a post endurance check showed normal cycling.

Oxygen concentrations measured after the copper tube change were lower (87-88 percent) than anticipated (92 percent) and may be attributed to the following:

The OAES was operating for some time in the cracked tube condition causing an imbalance in bed pressure (c.10 psig). Once the imbalance is corrected, the system needs time to 'recover', resulting in lower concentrations in the interim.

Figure 74 — OEAS Concentrator Structural Failures

Air or oxygen leaks in the system after repair.

High level endurance vibration resulted in a 'hot' unit with possible heat transfer to the molecular sieve pellets.

Functional level testing in the vertical attitude (5 minutes, 24.2 Grms) was attempted. The OEAS stopped cycling 2 minutes into the test. Voltages on the terminal strip of the electronics module showed normal operation. Later inspection at Bendix revealed a cracked snap ring in the motor assembly resulting in physical prevention of valve turning. This structural failure has also been attributed to screw clamp disconnection.

The structural failures experienced should be addressed further. The aluminum tube crack of S/N E1, although causing a large drop in oxygen concentration, is not considered serious as it had occurred after 18 hours of vibration. These tubes, however, will be replaced with stainless steel. It can be assumed that the copper tube and snap ring failures were a result of carelessness in assembly, as the clamps were backed out completely and not broken. The structural integrity of the unit had also been demonstrated in previous attempts.

A breakdown in hours of vibration accomplished on each unit is presented in Table 9.

Acceleration

The concentrator was acceleration tested in accordance with MIL-STD-810C, Method 513.2, Procedure II, utilizing the Dynamic Flight Simulator (centrifuge) of the Naval Air Development Center. The G levels and directions were as follows, based on unit orientation in the lox bay. The plateau time for each run was 15 seconds.

Direction	G Level
Gx	2.0
-Gx	6.0
±Gy	4.0
Gz	9.0
-Gz	3.0

During these runs, the unit was operating, supplied with air at 25 psig, 28 VDC and a set flow of 13.1 lpm of enriched air drawn from the unit. Oxygen concentration, however, was not monitored throughout each run.

Initial acceleration testing was unsuccessful, revealing a drop in motor power consumption (1.3 in lieu of 1.92 amps @ 28 VDC) when a post test bench check was made. Although still capable of operation, any further environmental stress could have resulted in a complete motor stop. After incorporation of tantalum capacitors within the module (part of the vibration modifications discussed previously), the unit successfully passed acceleration testing, showing no deviation in oxygen concentration, outlet pressure, power consumption, or cycle time. No structural damage was evident at the conclusion of the tests.

Shock

The OEAS Oxygen Concentrator was shock tested in accordance with MIL-STD-810C, Method 516.2, Procedure I, Basic Design Test. The unit was first placed in its normal mounting attitude and shocked three times with a pulse conforming to Figure 75. Three shocks in each of the other directions were applied for a total of 18 shocks. The concentrator was not operating during the exposure, although power consumption (motor/solenoid and heaters) were verified after each shock.

Table 9

OEAS CONCENTRATOR VIBRATION SUMMARY

				S/N 806004E		S/N E1		S/N E2	
	Grms	Test	Axis	Unit Fully Operational	Unit Damaged	Unit Fully Operational	Unit Damaged	Unit Fully Operational	Unit Damaged
MIL-STD-810C	16.4	Functional	X (Long)	1.75	0.25 (E)	–	–	–	–
	16.4	Functional	Y (Lat)	–	–	–	–	–	–
	16.4	Functional	Z (Vert)	–	–	0.5	–	–	–
	29.5	Endurance	X	–	1.0 (S)	–	–	–	–
	32.2	Endurance	X	–	4.0 (E)	–	–	–	–
	32.2	Endurance	Y	–	3.0 (E)	–	–	–	–
	32.2	Endurance	Z	–	3.0 (E)	0.5	0.5 (E)	–	–
MDC A3780	7.3	Functional	X	–	–	0.42	–	0.42	–
	7.3	Functional	Y	–	–	0.42	–	0.42	–
	7.3	Functional	Z	–	–	0.42	0.42 (S)	–	0.42 (S)
	19.7	Functional	X	–	–	0.08	–	0.08	–
	19.7	Functional	Y	–	–	0.08	–	0.08	–
	24.2	Functional	Z	–	–	0.08	0.08 (S)	–	0.08 (S)
	19.7	Endurance	X	–	–	6.0	–	3.0	3.0 (S)
	19.7	Endurance	Y	–	–	6.0	–	3.0	3.0 (S)
	24.2	Endurance	Z	–	–	–	3.0 (E) 3.0 (S)	3.0	3.0 (S)
		(E) Electronically		1.75	11.25	14.50	7.0	10.0	9.5
		(S) Structurally		13.0		21.50		19.5	

54.0 Total Hours

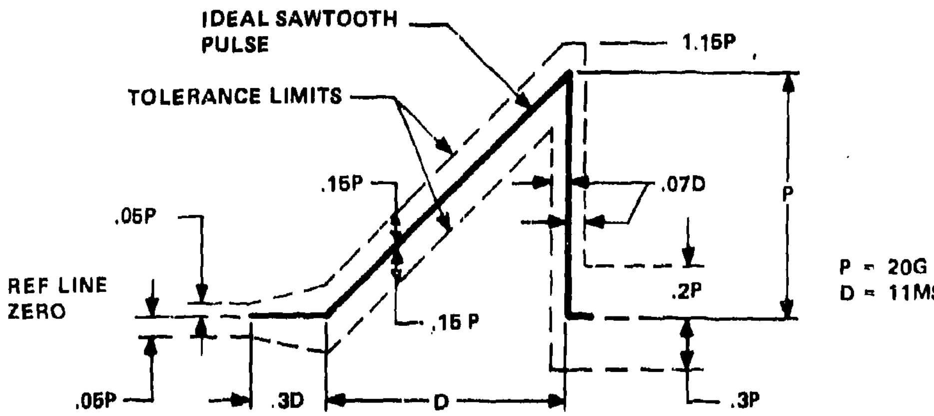


Figure 75 — OEAS Concentrator Shock Pulse

A visual examination after all testing revealed no structural deficiencies while the unit showed no deviation with respect to cycle time, power consumption, heater activation, outlet pressure, or oxygen concentration.

Dust (Fine Sand)

The OEAS Concentrator was dust tested in accordance with MIL-STD-810C, Method 510.1, Procedure I. The concentrator was not operating during the exposure, with air inlet, oxygen outlet, nitrogen exhaust and electrical ports capped. The concentrator was subjected to dust particles (149 micron maximum) with a density of 0.3 ± 0.2 grams per cubic foot and air velocity of 1750 ± 250 feet per minute at an ambient temperature of 73°F for a six hour period. Air velocity was reduced to 300 ± 200 feet per minute, with chamber temperature raised to 145°F for a period of 16 hours. Air velocity was then raised to initial speed for a period of 6 hours while maintaining 145°F.

Removal of the thermal shroud after test completion revealed heavy accumulation of dust on the electronic box, filter housing, and control valve motor. A functional check one hour after test completion showed normal power consumption, heater activation and cycle time. However, raising inlet pressure to 35 psig resulted in an outlet pressure of 30 psig (an inlet pressure of 45 psig is necessary for an outlet pressure of 30 psig with this concentrator). Outlet pressure fell to its normal valve within 30 seconds, while continued operation with inlet pressures of 45 and 60 psig showed normal operation. The entrance of dust into the pressure reducer through the ports which reference ambient pressure is a possibility, resulting in temporary seating interference.

Salt Fog

The OEAS Concentrator was salt fog tested in accordance with MIL-STD-810C, Method 509.1, Procedure I. The salt solution specified, however, was not utilized. A solution which duplicates the effects of a marine atmosphere (Table 10) taken from MIL-E-81910A(AS) (16) was employed. The unit was suspended within the test chamber, exposing all sides to the atmosphere. Inlet air, oxygen outlet, nitrogen exhaust and electrical connection ports were capped. The unit was exposed to this atmosphere for 48 hours at an ambient temperature of 95°F and was not operating during the exposure.

Table 10

SALT FOG SOLUTION

Salt	Grams Per Liter
Sodium Chloride	24.540
Magnesium Chloride	11.110
Sodium Sulfate	4.094
Calcium Chloride	1.159
Potassium Chloride	0.695
Sodium Bicarbonate	0.201
Potassium Bromide	0.101
Strontium Chloride	0.042
Boric Acid	0.027
Sodium Fluoride	0.003

Although visual inspections revealed no structural degradation, functional checks conducted 90 minutes after the test conclusion showed the following electronic anomalies (1) non-activation of the thermal control system solenoid, resulting in motor circuit current draw of 1.92 amps (2.3 normal), (2) continuous activation of heater number one, resulting in excessive bed inlet temperatures, (3) heater activation without power to the motor circuit and (4) excessive surface temperatures of electrical connector bracketry (external to shroud). With the same anomalies evident 24 hours later, the unit was returned for repair.

The apparent cause for failure has been determined to be voltage in excess of 80V applied to a transistor deep within the electronics module. The defective transistor was replaced (with no design change made) and operation resumed as normal. The specific cause for overvoltage was placed on transits in the external power supply on start up. With no analysis of salt compound/moisture induced arcing on leads external to the module, salt fog retesting was accomplished and found successful.

BREATHING REGULATOR

Results for the OEAS Breathing Regulator testing program are as follows, based on the data presented in reference 24.

Outlet Pressure (Initial)

Outlet pressures were measured for both regulators as received in accordance with MIL-R-81553 (AS). Table 1 of the specification was replaced with the following.

Inlet Supply Pressure (psig)	Ambient Flow (lpm)	Altitude (feet)	Outlet Pressure (in H_2O)
5	0 to 50	Sea Level	0 to 1.5
10	0 to 80	Sea Level	0 to 1.5
25	0 to 100	Sea Level	0 to 1.5
70	0 to 100	Sea Level	0 to 1.5
120	0 to 100	Sea Level	0 to 1.5
15	0 to 70	30,000	0 to 1.5
70	0 to 100	30,000	0 to 1.5

Inlet Supply Pressure (psig)	Ambient Flow (lpm)	Altitude (feet)	Outlet Pressure (in H_2O)
120	0 to 100	30,000	0 to 1.5
15	0 to 100	36,000	3.5 to 5.5
70	0 to 100	36,000	3.5 to 5.5
120	0 to 100	36,000	3.5 to 5.5
15	0 to 100	40,000	8.0 to 10.5
70	0 to 100	40,000	8.0 to 10.5
120	0 to 100	40,000	8.0 to 10.5
15	0 to 100	45,000	13 to 16
70	0 to 100	45,000	13 to 16
120	0 to 100	45,000	13 to 16
15	0 to 100	50,000	16 to 20
70	0 to 100	50,000	16 to 20
120	0 to 100	50,000	16 to 20

Results for the outlet pressure tests are presented in Table 11. Both regulators had outlet pressures which were out of specification limits at altitude, dependent upon minimum and maximum inlet pressure. S/N 10E remained within specification limits at minimum (15 psig) and rose above specification maximum with 120 psig inlet pressure. The converse is true for S/N 11E, particularly at 45,000 feet. Increasing, then decreasing inlet pressure and altitude of 11E showed the non-repeatability of outlet pressure where deviations of as much as 1.0 inch of water were revealed.

Noise Level

Noise level tests were conducted in accordance with MIL-R-81553, with inlet pressures of 25 and 120 psig. In addition to the standard system (chest mounted configuration) noise level was conducted utilizing the personnel hose assembly (with MBU-14/P hose from CRU-60/P to A-13A mask). Results are presented in Table 12 which shows excessive dB levels measured on the standard system at 6400 Hz, and a large noise level reduction at 5000 and 6400 Hz through use of the personnel hose assembly.

Body Leakage

The body leakage test of MIL-R-81553 was replaced with a test for measurement of regulator "bleed", a set flow which passes through the capillary type orifice and exits through ambient ports. Actual body leakage (through screws, etc.) cannot be measured due to possible demand valve leakage if bleed ports are capped. Bleed flow should not exceed 750 cc/min with an inlet pressure of 70 psig and the outlet capped. Bleed for each regulator was measured as follows: S/N 10E, 450 cc/min; S/N 11E, 250 cc/min.

Demand Valve Leakage

Both regulators were subjected to inlet pressures of 5 and 120 psig while maintaining zero flow conditions at sea level. Results were satisfactory as outlet pressures (approximately 1.3 in H_2O) measured after a five minute period were identified to those measured initially.

Overload

A pressure of 25 inches of water was applied to the outlet port with the inlet capped. Results for both regulators were satisfactory, as no leakage or damage was evident.

Table 11

OUTLET PRESSURE (INITIAL)

Test Altitude (Feet)	Spec Limit (Inches of Water)	OUTLET PRESSURE (INCHES OF WATER) S/N IOE																			
		INLET PRESSURE (PSIG)																			
		5 Psig			10 Psig			15 Psig					25 Psig			70 Psig			120 Psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100	0	50	100
Sea Level		1.00	.90	.85	1.10	.95	.70	X	X	X	X	X	.75	.65	.60	.95	.65	.45	1.10	.70	.50
30000	0 to 1.5	X	X	X	X	X	X	1.00	.95	X	1.10	X	X	X	X	1.10	1.05	.90	1.50	1.50	1.35
36000	3.5 to 5.5	X	X	X	X	X	X	5.10	X	4.95	X	4.85	X	X	X	5.20	5.05	4.70	5.90	5.95	6.05
40000	8.0 to 10.5	X	X	X	X	X	X	9.85	X	9.75	X	9.85	X	X	X	10.40	10.10	10.20	11.15	11.05	11.00
45000	13.0 to 16.0	X	X	X	X	X	X	14.85	X	14.85	X	14.95	X	X	X	15.85	15.45	15.20	16.25	16.25	16.30
50000	16.0 to 20.0	X	X	X	X	X	X	19.10	X	18.85	X	18.90	X	X	X	19.90	19.55	19.35	*	*	20.3

*Greater than 20.3 inches of water

Test Altitude (Feet)	Spec Limit (Inches of Water)	OUTLET PRESSURE (INCHES OF WATER) S/N 11E																			
		INLET PRESSURE (PSIG)																			
		5 Psig			10 Psig			15 Psig					25 Psig			70 Psig			120 Psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100	0	50	100
Sea Level		1.20	1.05	.95	1.20	1.15	.80	X	X	X	X	X	1.20	1.05	1.00	1.20	.90	.95	1.10	.85	.85
30000	0 to 1.5	X	X	X	X	X	X	1.05	.85	X	.95	X	X	X	X	1.10	.80	.95	1.30	1.00	1.20
36000	3.5 to 5.5	X	X	X	X	X	X	4.45	X	4.05	X	4.15	X	X	X	5.00	4.60	4.40	5.35	5.10	5.25
40000	8.0 to 10.5	X	X	X	X	X	X	9.50	X	9.00	X	9.10	X	X	X	9.90	9.70	9.70	10.30	9.75	9.95
45000	13.0 to 16.0	X	X	X	X	X	X	12.00	X	11.90	X	12.00	X	X	X	14.55	14.50	14.90	15.10	14.50	14.90
50000	16.0 to 20.0	X	X	X	X	X	X	16.15	X	15.75	X	15.95	X	X	X	18.55	18.40	18.25	18.80	18.25	18.70

Table 12

BREATHING REGULATOR NOISE LEVEL CONTROL TEST RESULTS

Noise Level (dB)[1]

Freq. (Hz)	Limit (dB)	S/N 808010E				S/N 810011E			
		1	2	3	4	1	2	3	4
320	95	90	89	88	88	91	91	87	88
400	95	91	91	88	66	91	90	86	80
500	95	90	91	87	87	89	88	83	83
640	95	89	90	86	86	87	87	83	84
800	95	87	87	81	81	85	84	77	80
1000	90	82	83	74	74	80	79	73	74
1250	85	80	80	72	73	77	76	72	71
1600	85	83	82	80	82	80	82	80	77
2000	90	87	87	85	87	87	86	84	84
2500	90	84	85	83	83	84	84	82	82
3200	85	84	84	84	83	85	85	83	83
4000	90	75	77	73	74	76	77	73	73
5000	85	81	83	72	76	82	83	74	73
6400	85	89[2]	91[2]	76	75	91[2]	90[2]	78	75

[1]Tolerance ± 2 dB

Test Condition 1 – 25 psig, Standard System
2 – 120 psig, Standard System
3 – 25 psig, Personnel Hose Assembly
4 – 120 psig, Personnel Hose Assembly

[2]Out of Specification

While maintaining a zero flow condition at sea level, a pressure of 150 psig was applied to the inlet of both regulators for 3 minutes. Results were satisfactory, as outlet pressure measured (1.3 in H_2O) did not exceed the maximum of 2.5 inches of water allowed.

Post overload outlet pressures were measured and are presented in Table 13. A definite shift in outlet pressure was evident with S/N 11E, which was initially low at 15 psig was then well within specification with an inlet pressure as low as 5 psig. Although minimum regulator supply pressures at altitude on the AV-8A will not fall this low, additional tests were added at 5 psig to evaluate regulator performance in the event supply pressures available on future aircraft approach this design minimum. S/N 10E has also shown outlet pressures within specification at 5 psig while still out of specification at 120 psig. Additional testing revealed that 10E would remain within specification at maximum inlet pressures of 85-95 psig, depending on altitude. The direct cause of the positive shift in outlet pressure is not known. Effects of overload such as clearing of bleed ports, readjustment of aneroid seating, etc. are possible.

Table 13

POST OVERLOAD OUTLET PRESSURE

Test Altitude (Feet)	Spec Limit (Inches of Water)	OUTLET PRESSURE (INCHES OF WATER) S/N 10E — INLET PRESSURE (PSIG)																			
		5 Psig			10 Psig			15 Psig					25 Psig			70 Psig			120 Psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100	0	50	100
Sea Level		.95	.85	.85	.95	X	.85	X	X	X	X	X	.95	X	1.20	.75	.75	.95	1.00	X	1.00
30000	0 to 1.5	X	.65	.70	X	X	X	1.15	X	X	1.10	X	X	X	X	1.00	.90	.90	1.70	X	1.45
36000	3.5 to 5.5	X	4.30	4.50	X	X	X	4.40	X	X	X	4.30	X	X	X	5.30	5.30	5.40	5.85	X	5.75
40000	8.0 to 10.5	X	9.75	9.75	X	X	X	9.80	X	X	X	9.60	X	X	X	10.45	10.40	10.45	11.00	X	10.80
45000	13.0 to 16.0	X	14.50	14.65	X	X	X	14.70	X	X	X	14.65	X	X	X	15.70	15.65	15.65	16.40	X	16.10
50000	16.0 to 20.0	X	16.50	18.00	X	X	X	18.80	X	X	X	18.85	X	X	X	19.70	19.70	19.80	*	*	*

*Gre r than 20.3 inches of water

Test Altitude (Feet)	Spec Limit (Inches of Water)	OUTLET PRESSURE (INCHES OF WATER) S/N 11E — INLET PRESSURE (PSIG)																			
		5 Psig			10 Psig			15 Psig					25 Psig			70 Psig			120 Psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100	0	50	100
Sea Level		.95	.90	.90	.80	X	.75	X	X	X	X	X	.70	X	1.00	X	X	X	.80	X	.75
30000	0 to 1.5	X	.90	.90	X	X	X	.95	.80	X	.85	X	X	X	X	X	X	X	1.10	X	1.10
36000	3.5 to 5.5	X	4.10	4.35	X	X	X	4.55	X	4.50	X	4.80	X	X	X	X	X	X	5.25	X	4.90
40000	8.0 to 10.5	X	9.20	9.40	X	X	X	9.75	X	9.60	X	9.70	X	X	X	X	X	X	10.10	X	9.90
45000	13.0 to 16.0	X	14.35	14.50	X	X	X	14.80	X	14.65	X	14.85	X	X	X	X	X	X	15.50	X	15.20
50000	16.0 to 20.0	X	18.20	18.25	X	X	X	18.85	X	18.60	X	18.80	X	X	X	X	X	X	18.80	X	18.70

High Temperature

The breathing regulators were subjected to high ambient temperature testing in accordance with MIL-R-81553 (AS). Each was conditioned at a temperature of 160°F for a period of three hours. After conditioning, and while at 160°F, outlet pressure tests were conducted, Tolerances of ±1.0 inch of water were added to outlet pressure limits to allow for any aneroid calibration shift. Results for each regulator are presented in Table 14. The only out of 'normal' specification values were found with S/N 10E with an inlet pressure of 120 psig.

After stabilization at room temperature, outlet pressure was again checked on each regulator, the results of which are presented in Table 15. Above specification maximums were again measured on S/N 10E at 36000 feet or above with an inlet pressure of 120 psig. Below specification minimum values were measured on S/N 11E at 36000 feet with an inlet pressure of 15 psig. Post high temperature bleed flows were measured as follows: S/N 10E – 540 cc/min; S/N 11E – 385 cc/min. Demand valve leakage tests were satisfactory for each regulator with an inlet pressure of 5 psig. Discrepancies were evident when tested with 120 psig, as outlet pressure increased from 1.45 to 1.60 inches of water on S/N 10E and from 1.30 to 1.40 inches of water on S/N 11E after the five minute period.

Low Temperature

The breathing regulators were subjected to low ambient temperature testing in accordance with MIL-R-81553 (AS). Each was conditioned at a temperature of -65°F for a period of three hours. After conditioning, and while at -65°F, outlet pressure tests were conducted. Again, tolerances of ± 1.0 inch of water were added to outlet pressure limits. Results for each regulator are presented in Table 16. Although all values measured are within specification limits with the tolerances added, out of normal values were evident with S/N 10E with an inlet pressure of 120 psig, and with S/N 11E with 15 psig inlet at 36000 and 40000 feet.

After stabilization at room temperature, outlet pressure was again checked on each regulator, the results of which are presented in Table 17. Above specification maximums were evident with S/N 10E, while below specification minimums were measured on S/N 11E with an inlet pressure of 15 psig at 36000, 40000 and 45000 feet. S/N 11E has also shown a downward shift of outlet pressure at all altitudes with an inlet pressure of 15 psig when compared with post high temperature values measured. Post low temperature bleed flows were found to be 440 cc/min for S/N 10E and 175 cc/min for S/N 11E. Discrepancies were again evident with demand valve leakage testing, as both regulators showed an increase of 0.1 inches of water with an inlet of 5 psig. S/N 10E decreased by 0.3 while S/N 11E increased by 0.2 inches of water outlet pressure when tested with an outlet pressure of 120 psig after the five minute period.

The discrepancies evident with S/N 11E resulted in a return of this regulator to the vendor for analysis. Aneroid disassembly revealed three scratches in the seat, which coupled with the decrease in bleed flow, which resulted in the outlet pressure shift downward. The cause of the scratches is not known, as inlet (screen) and outlet (noise suppression) filters should preclude the entrance of foreign material. Bleed flow was increased to 385 cc/min and the aneroid recalibrated. The seat, however, was not replaced or repaired.

Table 14

BREATHING REGULATOR HIGH TEMPERATURE OUTLET PRESSURES

Serial Number 10E

Test Altitude in Feet	Spec. Limit (inches of water)	Outlet Pressure (inches of water)										
		5 psig		10 psig		15 psig			25 psig		120 psig	
		Flow (lpm)		Flow		Flow			Flow		Flow	
		0	50	0	80	0	70	100	0	100	0	100
Sea Level		0.85	0.90	1.00	-0.35*	X	X	X	1.00	1.10	1.20	1.45
30,000	0 to 2.5	X	X	X	X	0.70	0.70	X	X	X	1.40	1.10
35,000	2.5 to 6.5	X	X	X	X	4.35	X	4.40	X	X	5.85	5.70
40,000	7.0 to 11.5	X	X	X	X	9.40	9.25	X	X	X	10.75	10.65
45,000	12.0 to 17.0	X	X	X	X	14.50	X	14.55	X	X	13.00	15.85
50,000	15.0 to 21.0	X	X	X	X	18.85	X	18.70	X	X	20.15	20.00

*Out of specification; 1.00 inches of water with inlet pressure increased to 11 psig.

Serial Number 11E

Test Altitude in Feet	Spec. Limit (inches of water)	Outlet Pressure (inches of water)										
		5 psig		10 psig		15 psig			25 psig		120 psig	
		Flow (lpm)		Flow		Flow			Flow		Flow	
		0	50	0	80	0	70	100	0	100	0	100
Sea Level		1.05	1.00	0.95	1.10	X	X	X	1.00	1.05	0.95	0.80
30,000	0 to 2.5	X	X	X	X	0.85	0.85	X	X	X	1.20	1.00
35,000	2.5 to 6.5	X	X	X	X	3.90	X	3.90	X	X	5.00	4.80
40,000	7.0 to 11.5	X	X	X	X	8.90	X	8.90	X	X	10.00	9.90
45,000	12.0 to 17.0	X	X	X	X	14.35	X	14.35	X	X	15.05	14.85
50,000	15.0 to 21.0	X	X	X	X	17.95	X	17.95	X	X	19.05	18.75

Table 15

BREATHING REGULATOR POST HIGH TEMPERATURE OUTLET PRESSURES

Serial Number 10E

Test Altitude in Feet	Spec. Limit (inches of water)	Outlet Pressure (inches of water)										
		5 psig		10 psig		15 psig			25 psig		120 psig	
		Flow (lpm)		Flow		Flow			Flow		Flow	
		0	50	0	80	0	70	100	0	100	0	100
Sea Level		0.85	0.90	0.75	-0.70[1]	X	X	X	1.00	1.25	1.10	1.15
30,000	0 to 1.5	X	X	X	X	1.00	0.95	X	X	X	1.50	1.45
35,000	3.5 to 5.5	X	X	X	X	4.50	X	4.50	X	X	6.10*	6.10*
40,000	8.0 to 10.5	X	X	X	X	9.45	X	9.75	X	X	11.05*	11.05*
45,000	13.0 to 16.0	X	X	X	X	14.85	X	14.90	X	X	16.30*	16.30*
50,000	16.0 to 20.0	X	X	X	X	18.90	X	18.75	X	X	2	20.3*

*Out of specification.

[1] 1.00 inches of water with inlet pressure increased to 11 psig.

[2] Greater than 20.3 inches of water.

Serial Number 11E

Test Altitude in Feet	Spec. Limit (inches of water)	Outlet Pressure (inches of water)										
		5 psig		10 psig		15 psig			25 psig		120 psig	
		Flow (lpm)		Flow		Flow			Flow		Flow	
		0	50	0	80	0	70	100	0	100	0	100
Sea Level		0.85	0.90	1.00	0.80	X	X	X	1.10	0.80	0.90	0.75
30,000	0 to 1.5	X	X	X	X	1.10	0.90	X	X	X	1.10	1.00
35,000	3.5 to 5.5	X	X	X	X	2.95*	X	3.00*	X	X	4.25	4.10
40,000	8.0 to 10.5	X	X	X	X	8.10	X	8.10	X	X	9.20	8.90
45,000	13.0 to 16.0	X	X	X	X	13.25	X	13.25	X	X	14.40	14.15
50,000	16.0 to 20.0	X	X	X	X	17.25	X	17.10	X	X	18.50	18.10

*Out of specification.

Table 16

BREATHING REGULATOR LOW TEMPERATURE OUTLET PRESSURES

Serial Number 10E

Test Altitude In Feet	Spec. Limit (Inches of water)	Outlet Pressure (Inches of water)										
		5 psig		10 psig		15 psig			25 psig		120 psig	
		Flow (lpm)		Flow		Flow			Flow		Flow	
		0	50	0	80	0	70	100	0	100	0	100
Sea Level		0.90	0.40	1.05	0.80	X	X	X	1.00	1.05	1.10	0.95
30,000	0 to 2.5	X	X	X	X	1.15	1.00	X	X	X	1.60	1.95
35,000	2.5 to 6.5	X	X	X	X	4.75	X	4.65	X	X	6.50	6.40
40,000	7.0 to 11.5	X	X	X	X	9.80	X	9.80	X	X	11.50	11.45
45,000	12.0 to 17.0	X	X	X	X	14.90	X	15.00	X	X	16.80	16.75
50,000	15.0 to 21.0	X	X	X	X	19.25	X	19.10	X	X	18.75	18.50

Serial Number 11E

Test Altitude In Feet	Spec. Limit (Inches of water)	Outlet Pressure (Inches of water)										
		5 psig		10 psig		15 psig			25 psig		120 psig	
		Flow (lpm)		Flow		Flow			Flow		Flow	
		0	50	0	80	0	70	100	0	100	0	100
Sea Level		1.20	0.90	1.30	1.40	X	X	X	1.25	1.40	1.00	1.75
30,000	0 to 2.5	X	X	X	X	1.30	1.10	X	X	X	1.70	1.60
35,000	2.5 to 6.5	X	X	X	X	2.90	X	2.90	X	X	4.70	4.45
40,000	7.0 to 11.5	X	X	X	X	7.90	X	7.90	X	X	9.40	9.40
45,000	12.0 to 17.0	X	X	X	X	13.10	X	13.15	X	X	14.75	12.70
50,000	15.0 to 21.0	X	X	X	X	17.15	X	17.30	X	X	16.30	16.20

Table 17

BREATHING REGULATOR POST LOW TEMPERATURE OUTLET PRESSURES

Serial Number 10E

Test Altitude in Feet	Spec. Limit (inches of water)	Outlet Pressure (inches of water)										
		5 psig		10 psig		15 psig			25 psig		120 psig	
		Flow (lpm)		Flow		Flow			Flow		Flow	
		0	50	0	80	0	70	100	0	100	0	100
Sea Level		0.95	1.15	1.05	0.85	X	X	X	1.00	0.65	1.05	0.55
30,000	0 to 1.5	X	X	X	X	1.05	1.10	X	X	X	1.60	1.50
35,000	3.5 to 5.5	X	X	X	X	4.60	X	4.70	X	X	5.95*	6.25*
40,000	8.0 to 10.5	X	X	X	X	9.35	X	9.45	X	X	10.65*	10.80*
45,000	13.0 to 16.0	X	X	X	X	14.80	X	15.00	X	X	16.20*	16.35*
50,000	16.0 to 20.0	X	X	X	X	19.25	X	19.40	X	X	18.75	19.00

*Out of specification.

Serial Number 11E

Test Altitude in Feet	Spec. Limit (inches of water)	Outlet Pressure (inches of water)										
		5 psig		10 psig		15 psig			25 psig		120 psig	
		Flow (lpm)		Flow		Flow			Flow		Flow	
		0	50	0	80	0	70	100	0	100	0	100
Sea Level		1.00	1.05	1.10	1.10	X	X	X	1.05	1.70*	1.00	1.45
30,000	0 to 1.5	X	X	X	X	1.00	0.90	X	X	X	1.10	0.95
35,000	3.5 to 5.5	X	X	X	X	2.90*	X	2.85*	X	X	3.60	3.50
40,000	8.0 to 10.5	X	X	X	X	7.75*	X	7.45*	X	X	8.60	8.35
45,000	13.0 to 16.0	X	X	X	X	12.75*	X	12.75*	X	X	13.30	13.15
50,000	16.0 to 20.0	X	X	X	X	16.40	X	16.45	X	X	17.60	17.15

*Out of specification.

The regulator was again submitted to high and low temperature testing. High and post high temperature outlet pressures are presented in Tables 18 and 19, respectively. The only out of normal specification valves at high temperature were found with an inlet pressure of 120 psig. Post high temperature testing also showed satisfactory performance, with outlet pressures within specification with 5 psig and 15 psig at all altitudes and flows. Values for low and post low temperature testing repeat are presented in Tables 20 and 21. Again, outlet pressures were found within normal specification limits at low temperature with 5 and 15 psig inlet pressures, while post low temperature testing showed satisfactory performance with 15 psig inlet pressure at all altitudes and flows. Post low temperature bleed flow was found to be 400 cc/min.

Acceleration

The Breathing Regulator (S/N 10E) was acceleration tested in accordance with MIL-R-81553 (AS). However, the regulator was supplied with oxygen at an inlet pressure of 35 psig in lieu of the 50 to 120 specified. Prior to acceleration in each direction, outlet pressure (sea level) was recorded at 0, 50 and 100 lpm. The 100 lpm was continued while maintaining the 7g acceleration force. Outlet pressure was again measured at 0, 50 and 100 lpm after completion of each axis.

Outlet pressures measured during acceleration are presented in Table 22, with the corresponding acceleration directions shown in Figure 76. The only significant deviation in outlet pressure during acceleration occurred during forces 1 and 2, decreasing and increasing respectively, which may be expected as these forces are normal to the diaphragm. Although all outlet pressures remained within the specification limits of 0-1.5 inches of water and no visible damage to the regulator was evident, a discrepancy was found with an outlet pressure test at altitude (pressure breathing) after all acceleration.

The pre and post acceleration outlet pressures at altitude are presented in Table 23, where non-repeatability was once again evident. From these values, significant drops in outlet pressure (as much as 2.0 inches of water) were noted, although only one point (0 lpm @ 40,000 feet) was out of tolerance. When it became apparent that outlet pressure was degrading even further after endurance and storage (as presented in next section), acceleration testing was repeated after recalibration.

The outlet pressures during the second attempt are presented in Table 24, with pre and post acceleration altitude outlet pressures presented in Tables 25 and 26 respectively. The continued drop in outlet pressure was evident, large enough so that values measured with inlet pressures as high as 70 psig (@ 36,000 feet) were below specification minimum. Once again, the aneroid was recalibrated and the tests repeated.

Results for this third attempt are presented in Table 27 for outlet pressures during acceleration and in Tables 28 and 29 for pre and post pressure breathing values. Although a general trend of slight drops in outlet pressure was noted after acceleration, the degradation was far less dramatic than observed in previous attempts. With these results considered satisfactory, the second attempt at endurance was conducted.

Endurance

The Breathing Regulator (S/N 10E) was endurance tested in accordance with MIL-R-81553 (AS). This test consisted of 100,000 breathing cycles at sea level. A cycle rate of 15-19 cycles per minute, with oxygen supplied at 25 psig, was maintained with a flow rate of 30 lpm for 90,000 cycles, and 90 lpm for the final 10,000 cycles. Outlet pressures at altitude were checked before, after 64,000 cycles, and after all endurance testing. These values are presented in Table 30. Inspection of values measured at 15 psig at 36,000 feet revealed below minimum specification limits after 64,000 and 100,000 cycles. Checks with an inlet pressure of 5 psig showed a significant drop after all endurance testing, indicating some deficiency as a result of this test.

Table 18

S/N 11E HIGH TEMPERATURE OUTLET PRESSURE REPEAT

Test Altitude in Feet	Spec. Limit (inches of water)	Outlet Pressure (inches of Water)																
		Inlet Pressure (psig)																
		5 psig			10 psig			15 psig					25 psig			120 psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100
Sea Level		0.90	0.75	1.00	1.20	X	0.80	X	X	X	X	X	1.30	X	0.95	1.40	X	1.00
30,000	0 to 2.5	X	0.55	0.80	X	X	X	1.25	X	X	0.95	X	X	X	X	1.95	X	1.40
36,000	2.5 to 6.5	X	4.20	4.25	X	X	X	4.50	X	X	X	4.40	X	X	X	6.15	X	5.45
40,000	7.0 to 11.5	X	9.40	9.35	X	X	X	9.65	X	X	X	9.15	X	X	X	10.90	X	9.90
45,000	12.0 to 17.0	X	14.60	14.65	X	X	X	15.15	X	X	X	14.80	X	X	X	15.85	X	15.40
50,000	15.0 to 21.0	X	18.75	18.75	X	X	1	19.20	X	X	X	18.60	X	X	X	1	X	19.85

1 Greater than 20.3 inches of water

Table 19

S/N 11E Post High Temperature Outlet Pressure Repeat

Test Altitude in Feet	Spec. Limit (inches of water)	Outlet Pressure (inches of Water)																
		Inlet Pressure (psig)																
		5 psig			10 psig			15 psig					25 psig			120 psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100
Sea Level		0.90	0.80	0.70	1.00	X	0.80	X	X	X	X	X	1.15	X	1.10	1.40	X	1.00
30,000	0 to 1.5	X	0.80	0.90	X	X	X	1.10	X	X	0.95	X	X	X	X	1.60*	X	1.00
36,000	3.5 to 5.5	X	4.50	4.50	X	X	X	4.90	X	X	X	4.60	X	X	X	6.05*	X	5.60*
40,000	8.0 to 10.5	X	9.60	9.60	X	X	X	9.95	X	X	X	9.75	X	X	X	11.05*	X	10.80*
45,000	13.0 to 16.0	X	14.05	14.55	X	X	X	15.30	X	X	X	14.95	X	X	X	16.55*	X	15.95
50,000	16.0 to 20.0	X	16.80	17.45	X	X	X	17.90	X	X	X	17.85	X	X	X	19.75	X	19.20

*Out of specification.

Table 20

S/N 11E LOW TEMPERATURE OUTLET PRESSURE REPEAT

Test Altitude in Feet	Spec. Limit (inches of water)	Outlet Pressure (inches of Water)																
		Inlet Pressure (psig)																
		5 psig			10 psig			15 psig					25 psig			120 psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100
Sea Level		1.05	0.85	0.85	1.25	X	-0.35*	X	X	X	X	X	1.20	X	1.30	1.00	X	1.20
30,000	0 to 2.5	X	1.30	1.30	X	X	X	1.30	X	X	1.30	X	X	X	X	1.90	X	1.90
36,000	2.5 to 6.5	X	4.55	4.75	X	X	X	5.05	X	X	X	4.50	X	X	X	6.30	X	6.10
40,000	7.0 to 11.5	X	10.05	9.65	X	X	X	10.25	X	X	X	9.60	X	X	X	11.70	X	11.50
45,000	12.0 to 17.0	X	14.05	14.20	X	X	X	14.80	X	X	X	14.80	X	X	X	16.70	X	16.50
50,000	15.0 to 21.0	X	17.40	17.70	X	X	X	18.85	X	X	X	17.95	X	X	X	20.00	X	19.20

*Out of specification

Table 21

S/N 11E POST LOW TEMPERATURE OUTLET PRESSURE REPEAT

Test Altitude in Feet	Spec. Limit (inches of water)	Outlet Pressure (inches of Water)																
		Inlet Pressure (psig)																
		5 psig			10 psig			15 psig					25 psig			120 psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100
Sea Level		1.00	0.75	0.95	1.15	X	-0.80*	X	X	X	X	X	1.40	X	1.20	1.30	X	1.20
30,000	0 to 1.5	X	1.05	1.00	X	X	X	1.40	X	X	1.10	X	X	X	X	2.30*	X	1.65*
36,000	3.5 to 5.5	X	4.50	4.30	X	X	X	4.60	X	X	X	4.40	X	X	X	6.15*	X	5.85*
40,000	8.0 to 10.5	X	8.30	8.65	X	X	X	9.95	X	X	X	9.75	X	X	X	10.50	X	10.35
45,000	13.0 to 16.0	X	14.10	14.30	X	X	X	14.80	X	X	X	14.70	X	X	X	15.80	X	15.20
50,000	16.0 to 20.0	X	15.40*	15.45*	X	X	X	17.25	X	X	X	17.15	X	X	X	16.25	X	16.10

*Out of specification

Table 22

BREATHING REGULATOR ACCELERATION OUTLET PRESSURES (FIRST ATTEMPT)

Test Direction @ 7g	Spec. Limits H_2O''	Outlet Pressures (inches of water) 35 PSIG Inlet Pressure Outlet Flows (LPM) Pre Test			At 7 g's			Post Test		
		0	50	100	0	50	100	0	50	100
F_1	0 – 1.5	1.00	0.75	0.90	0.30	0.30	0.25	0.95	0.80	0.85
F_2	0 – 1.5	1.00	0.75	0.85	1.20	1.20	1.20	0.95	0.85	0.85
F_3	0 – 1.5	0.85	0.75	0.75	0.60	0.55	0.55	0.85	0.75	0.75
F_4	0 – 1.5	0.90	0.80	0.80	0.85	0.80	0.80	0.90	0.80	0.85
F_5	0 – 1.5	0.95	0.85	0.85	0.75	0.75	0.75	0.80	0.80	0.80
F_6	0 – 1.5	0.95	0.70	0.85	0.85	0.80	0.80	0.90	0.80	0.85

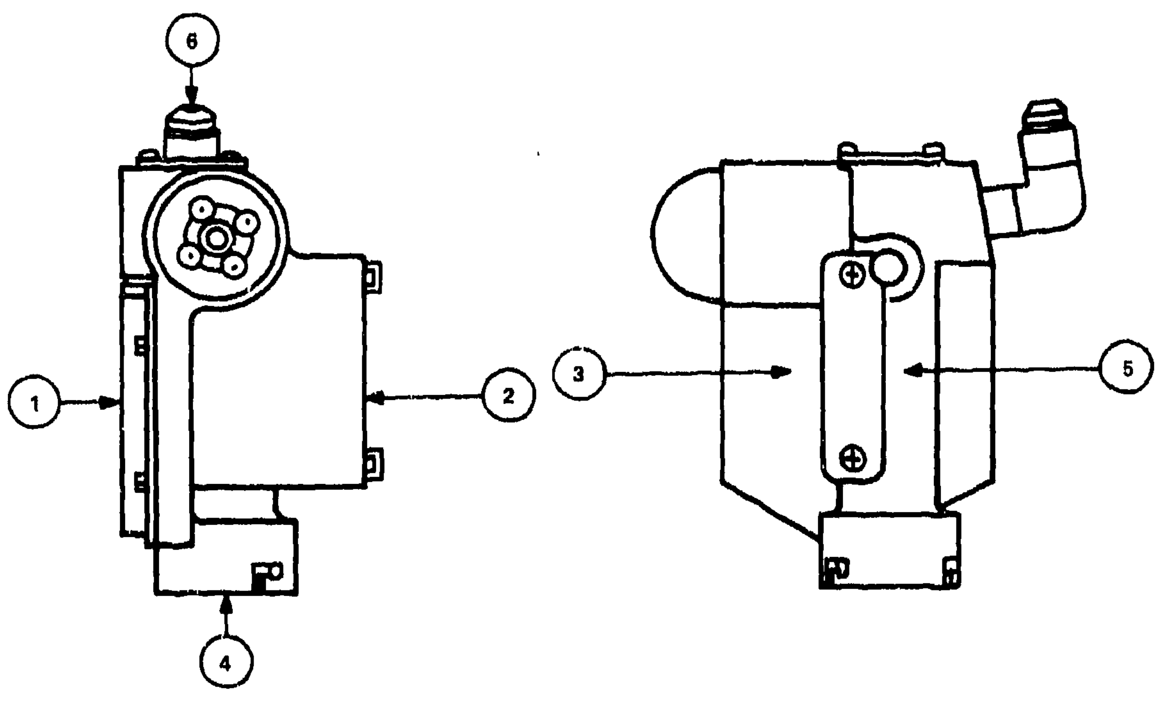


Figure 76 – Directions of Applied Acceleration

Table 23

BREATHING REGULATOR PRE AND POST ACCELERATION OUTLET PRESSURES (FIRST ATTEMPT)

Test Altitude in Feet	Spec. Limit (Inches of Water)	Outlet Pressure (inches of water)									
		Inlet Pressure (psig)									
		15 psig (pre)			15 psig (post)			60 psig (pre)		60 psig (post)	
		Flow (lpm)			Flow (lpm)			Flow (lpm)		Flow (lpm)	
		0	70	100	0	70	100	0	100	0	100
30,000	0 to 1.5	1.05	1.10	X	1.00	1.05	X	1.50	1.50	1.50	1.60
36,000	3.5 to 5.5	4.60	X	4.70	4.10	X	3.90	5.95	6.25	4.15	4.20
40,000	8.0 to 10.5	9.35	X	9.45	7.85	X	8.20	10.65	10.80	9.60	9.55
45,000	13.0 to 16.0	14.80	X	15.00	13.10	X	13.40	16.20	16.35	14.40	14.40
50,000	16.0 to 20.0	18.25	X	18.40	17.35	X	17.40	18.75	19.00	18.30	17.70

Table 24

BREATHING REGULATOR ACCELERATION OUTLET PRESSURES (SECOND ATTEMPT)

Test Direction	Spec. Limits H_2O''	Outlet Pressures (inches of water)								
		35 PSIG Inlet Pressure								
		Outlet Flows (LPM)								
		Pre Test			At 7 g's			Post Test		
		0	50	100	0	50	100	0	50	100
F_1	0 – 1.5	0.90	1.10	1.40	0.50	0.60	0.90	1.00	1.20	1.30
F_2	0 – 1.5	1.35	1.20	1.35	1.35	1.60	1.90	1.15	1.20	1.50
F_3	0 – 1.5	1.35	1.20	1.30	0.95	1.00	1.40	1.00	1.15	1.60
F_4	0 – 1.5	0.95	1.40	1.80	1.00	1.30	1.80	1.10	1.30	1.75
F_5	0 – 1.5	1.05	1.20	1.40	1.05	1.20	1.55	1.10	1.30	1.50
F_6	0 – 1.5	1.00	1.20	1.40	1.00	1.15	1.40	1.10	1.20	1.40

Table 25

BREATHING REGULATOR PRE-ACCELERATION OUTLET PRESSURES (SECOND ATTEMPT)

Test Altitude in Feet	Spec. Limit (inches of Water)	Outlet Pressure (inches of Water)																			
		Inlet Pressure (psig)																			
		5 psig			10 psig			15 psig					25 psig			70 psig			90 psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100	0	50	100
Sea Level		1.10	0.95	1.10	1.15	1.30	0.90	X	X	X	X	X	1.10	1.10	1.10	1.10	0.95	1.10	1.15	1.10	1.05
30,000	0 to 1.5	1.30	0.90	0.95	1.20	1.00	1.05	1.20	0.95	X	1.00	1.25	1.10	0.90	1.30	1.20	1.05	1.30	1.35	1.20	1.50
36,000	3.5 to 5.5	X	3.35*	3.20*	3.60	3.65	3.85	4.30	X	4.20	X	3.90	3.95	3.90	4.00	4.25	4.25	4.30	4.95	4.60	4.85
40,000	8.0 to 10.5	X	8.30	8.35	8.70	8.55	8.65	6.90	X	8.80	X	3.00	9.15	9.00	9.05	9.45	9.25	9.35	9.45	9.20	9.45
45,000	13.0 to 16.0	X	13.55	13.25	14.10	13.90	14.00	14.10	X	14.00	X	14.05	14.20	14.05	14.20	14.55	14.35	14.65	15.10	14.80	15.10
50,000	16.0 to 20.0	X	17.00	16.75	18.20	18.20	18.20	18.30	X	18.05	X	18.10	18.35	18.20	18.30	18.75	18.60	18.80	19.35	19.00	19.00

*Out of specification.

Table 26

BREATHING REGULATOR POST ACCELERATION OUTLET PRESSURES (SECOND ATTEMPT)

Test Altitude in Feet	Spec. Limit (inches of Water)	Outlet Pressure (inches of Water)																			
		Inlet Pressure (psig)																			
		5 psig			10 psig			15 psig					25 psig			70 psig			90 psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100	0	50	100
Sea Level		1.00	0.85	1.20	1.25	1.15	0.75	X	X	X	X	X	1.40	1.15	1.00	1.30	1.10	0.90	1.30	1.10	0.95
30,000	0 to 1.5	X	1.00	1.00	1.20	0.90	1.05	1.20	1.00	X	1.00	1.20	1.20	1.05	1.35	1.20	1.05	1.35	1.40	1.15	1.40
36,000	3.5 to 5.5	X	2.10*	2.05*	2.60*	2.20*	2.35*	2.75*	X	2.40*	X	2.55*	2.85*	2.50*	2.85*	3.75	3.10*	3.45*	3.80	3.70	3.65
40,000	8.0 to 10.5	X	7.25*	7.10*	7.70*	7.35*	7.50*	7.90*	X	7.60*	X	7.65*	7.90*	7.70*	7.90*	8.30	8.15	8.25	8.80	8.40	8.80
45,000	13.0 to 16.0	X	12.35*	12.00*	12.80*	12.70*	12.25*	12.85*	X	12.75*	X	12.90*	13.15	12.95*	13.10	13.55	13.55	13.55	13.80	13.40	13.70
50,000	16.0 to 20.0	X	14.55*	14.20*	16.75	16.40	16.70	17.10	X	17.00	X	16.80	16.95	16.75	16.90	17.50	17.45	17.40	18.00	17.70	17.90

*Out of specification.

Table 27

BREATHING REGULATOR ACCELERATION OUTLET PRESSURES (THIRD ATTEMPT)

Test Direction	Spec. Limits H_2O"	Outlet Pressures (Inches of water) — 35 PSIG Inlet Pressure — Outlet Flows (LPM)								
		Pre Test			At 7 g's			Post Test		
		0	50	100	0	50	100	0	50	100
F_1	0 – 1.5	0.85	1.00	0.80	0.55	0.30	0.25	0.95	1.00	0.55
F_2	0 – 1.5	1.00	1.00	0.75	1.35	1.25	1.30	0.90	1.00	0.80
F_3	0 – 1.5	0.90	0.90	0.60	1.00	0.90	0.70	0.95	1.00	0.55
F_4	0 – 1.5	0.90	0.95	0.70	0.95	0.85	0.60	0.95	1.00	0.70
F_5	0 – 1.5	0.85	0.90	0.55	1.05	0.90	0.85	0.95	1.00	0.75
F_6	0 – 1.5	0.90	1.00	0.70	0.95	0.85	0.95	1.00	1.10	0.90

When an outlet pressure check was conducted after one week of storage (no testing conducted in this period), an even further shift downward was evident, so much that outlet pressures were below minimum with 15 psig at 36, 40 and 45,000 feet for all flows and below minimum with 70 psig at 36,000 feet for all flows. This trend (downward shift) was believed to have initiated during acceleration testing. With acceleration testing repeated and successful on the third attempt, endurance testing was also repeated. Outlet pressure checks (Table 31) revealed good repeatability and within specification values with low inlet pressures. Demand valve leakage testing was also successful after endurance (no change in five minute period), and bleed flow found to be 540 cc/min.

Vibration

The sinusoidal vibration test of MIL-R-81553 was replaced, due to airframe mounting, by random vibration in accordance with MIL-STD-810C. One regulator (S/N 11E) was tested in accordance with Procedure IA, Equipment Category b.2. The power spectral densitites, variable frequency, and overall G rms for the test, based on use for 2000 missions and cabin location, were as follows:

	Functional Test	Endurance Test
G^2/Hz (PSD)	0.04	.2033
F var (Hz)	No inflection	88.6
G rms (G)	7.7	16.5

Table 28

BREATHING REGULATOR PRE-ACCELERATION OUTLET PRESSURES (THIRD ATTEMPT)

Test Altitude in Feet	Spec. Limit (inches of Water)	Outlet Pressure (inches of Water)																			
		Inlet Pressure (psig)																			
		5 psig			10 psig			15 psig					25 psig			70 psig			90 psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100	0	50	100
Sea Level		1.10	0.95	1.05	1.25	0.95	0.90	X	X	X	X	X	1.30	1.10	1.25	1.30	1.05	1.20	1.30	1.10	1.00
30,000	0 to 1.5	X	0.75	0.90	1.05	0.95	1.15	1.15	1.00	X	1.10	1.25	1.15	1.00	1.20	1.30	1.10	1.30	1.30	1.10	1.40
36,000	3.5 to 5.5	X	4.60	4.60	5.25	4.25	4.70	4.85	X	4.50	X	4.60	4.95	4.80	4.95	5.40	5.25	5.50	5.95*	5.75*	5.80*
40,000	8.0 to 10.5	X	8.80	8.90	9.80	9.70	9.75	10.05	X	9.90	X	9.95	10.00	9.90	10.20	10.70*	10.50	10.65*	11.05*	10.80*	10.80*
45,000	13.0 to 16.0	X	13.20	13.15	15.20	15.10	14.90	15.20	X	14.95	X	15.20	15.30	15.20	15.30	15.70	15.50	15.65	16.15*	15.90	16.00
50,000	16.0 to 20.0	X	16.55	16.50	19.25	19.10	19.05	19.30	X	19.15	X	19.20	19.50	19.35	19.40	19.75	19.65	19.75	20.30*	19.80	19.85

*Out of specification

Table 29

BREATHING REGULATOR POST ACCELERATION OUTLET PRESSURES (THIRD ATTEMPT)

Test Altitude in Feet	Spec. Limit (inches of Water)	Outlet Pressure (inches of Water)																			
		Inlet Pressure (psig)																			
		5 psig			10 psig			15 psig					25 psig			70 psig			90 psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100	0	50	100
Sea Level		1.20	1.00	1.15	1.20	1.15	1.10	X	X	X	X	X	1.20	1.20	1.25	1.35	1.20	1.20	1.25	1.20	1.10
30,000	0 to 1.5	X	1.00	0.95	1.10	1.00	1.00	1.15	1.00	X	1.10	1.30	1.20	1.10	1.40	1.25	1.10	1.40	1.50	1.20	1.50
36,000	3.5 to 5.5	X	4.10	3.85	4.70	4.30	4.70	4.60	X	4.25	X	4.30	4.85	4.65	4.90	5.70*	5.20	5.50	5.80*	5.50	5.80*
40,000	8.0 to 10.5	X	9.40	9.35	10.00	9.70	9.80	10.00	X	9.80	X	9.90	10.05	9.85	10.05	10.30	10.15	10.40	10.85*	10.50	10.75
45,000	13.0 to 16.0	X	12.85*	12.80*	14.95	14.75	14.70	15.00	X	14.85	X	14.75	15.20	15.05	15.20	15.60	15.15	15.65	16.00	15.75	15.85
50,000	16.0 to 20.0	X	17.60	17.20	19.15	18.90	18.80	19.15	X	19.05	X	19.10	19.30	19.15	19.25	19.65	19.50	19.55	20.00	19.70	19.85

*Out of specification.

Table 30

BREATHING REGULATOR PRE AND POST ENDURANCE TEST OUTLET PRESSURES (FIRST ATTEMPT)

Test Altitude in Feet	Spec. Limit (inches of Water)	Outlet Pressure (in H_2O) Pre-Endurance												
		5 psig inlet			10 psig		15 psig			25 psig		60 psig	
		Flow (lpm)			Flow		Flow			Flow		Flow	
		0	25	50	0	80	0	70	100	0	100	0	100
Sea Level		1.05	0.80	1.00	1.00	0.35	X	X	X	1.00	0.85	1.10	0.80
30,000	0 to 1.5	1.00	0.90	0.85	X	X	1.00	1.05	X	X	X	1.50	1.60
36,000	3.5 to 5.5	X	3.60	3.70	X	X	4.10	X	3.90	X	X	4.15	4.20
40,000	8.0 to 10.5	X	7.70*	7.70*	X	X	7.85*	X	8.20	X	X	9.60	9.55
45,000	13.0 to 16.0	X	12.50*	12.85*	X	X	13.10	X	13.40	X	X	14.40	14.40
50,000	16.0 to 20.0	X	17.10	17.10	X	X	17.35	X	17.40	X	X	18.30	17.70

Test Altitude in Feet	Spec. Limit (inches of Water)	Outlet Pressure (in H_2O) Post 64,000 Cycles												
		5 psig inlet			10 psig		15 psig			25 psig		60 psig	
		Flow (lpm)			Flow		Flow			Flow		Flow	
		0	25	50	0	80	0	70	100	0	100	0	100
Sea Level		0.90	0.90	1.10	1.00	1.10	X	X	X	1.05	1.40	1.00	1.30
30,000	0 to 1.5	X	0.95	0.85	X	X	0.90	1.05	X	X	X	1.10	1.25
36,000	3.5 to 5.5	X	2.45*	2.40*	X	X	2.75*	X	3.00*	X	X	3.55	3.60
40,000	8.0 to 10.5	X	7.85*	8.00	X	X	8.00	X	8.10	X	X	8.80	8.80
45,000	13.0 to 16.0	X	13.00	12.90*	X	X	13.20	X	13.25	X	X	13.80	13.75
50,000	16.0 to 20.0	X	17.00	16.90	X	X	17.25	X	17.40	X	X	17.75	17.85

Test Altitude in Feet	Spec. Limit (inches of Water)	Outlet Pressure (in H_2O) Post 100,000 Cycles												
		5 psig inlet			10 psig		15 psig			25 psig		60 psig	
		Flow (lpm)			Flow		Flow			Flow		Flow	
		0	25	50	0	80	0	70	100	0	100	0	100
Sea Level		0.95	0.90	1.20	1.10	1.05	X	X	X	1.10	1.20	1.10	1.20
30,000	0 to 1.5	X	1.00	1.05	X	X	1.10	1.15	X	X	X	1.20	1.40
36,000	3.5 to 5.5	X	2.25*	2.40*	X	X	3.00*	X	3.30*	X	X	3.50	3.40*
40,000	8.0 to 10.5	X	4.85*	4.00*	X	X	8.00	X	8.00	X	X	8.40	8.70
45,000	13.0 to 16.0	X	8.55*	8.05*	X	X	13.30	X	13.30	X	X	14.40	13.95
50,000	16.0 to 20.0	X	10.65*	10.20*	X	X	17.35	X	17.35	X	X	17.80	17.85

*Out of specification.

Table 31

BREATHING REGULATOR POST ENDURANCE OUTLET PRESSURES (SECOND ATTEMPT)

Test Altitude in Feet	Spec. Limit (inches of Water)	Outlet Pressure (inches of Water) After 10,000 Cycles (90 lpm)																			
		Inlet Pressure (psig)																			
		5 psig			10 psig			15 psig					25 psig			70 psig			90 psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100	0	50	100
Sea Level		1.20	0.35	1.25	1.25	1.10	0.90	X	X	X	X	X	X	X	X	1.30	1.10	0.90	X	X	X
30,000	0 to 1.5	X	0.95	0.90	1.20	1.00	1.05	1.20	1.00	X	1.10	1.15	X	X	X	1.30	1.05	1.35	X	X	X
36,000	3.5 to 5.5	X	4.50	4.30	4.80	4.60	4.80	4.70	X	4.40	X	4.90	X	X	X	5.65*	5.20	5.40	X	X	X
40,000	8.0 to 10.5	X	9.40	9.35	9.90	9.50	9.70	9.85	X	4.60	X	9.85	X	X	X	10.30	10.10	10.35	X	X	X
45,000	13.0 to 16.0	X	14.55	14.45	14.85	14.60	14.70	15.00	X	14.85	X	15.00	X	X	X	15.70	15.40	15.50	X	X	X
50,000	16.0 to 20.0	X	17.80	17.30	19.10	18.85	18.70	18.85	X	18.75	X	18.30	X	X	X	19.85	19.55	19.30	X	X	X

Test Altitude in Feet	Spec. Limit (inches of Water)	Outlet Pressure (inches of Water) After 90,000 Cycles (30 lpm)																			
		Inlet Pressure (psig)																			
		5 psig			10 psig			15 psig					25 psig			70 psig			90 psig		
		Flow (lpm)			Flow (lpm)			Flow (lpm)					Flow (lpm)			Flow (lpm)			Flow (lpm)		
		0	25	50	0	40	80	0	35	50	70	100	0	50	100	0	50	100	0	50	100
Sea Level		1.00	0.90	0.95	1.05	1.00	0.90	X	X	X	X	X	1.05	0.95	1.05	1.25	0.90	1.20	1.30	0.90	1.20
30,000	0 to 1.5	X	0.90	0.90	1.10	0.90	1.10	1.20	0.96	X	1.00	1.25	1.20	1.15	1.30	1.35	1.00	1.30	1.50	1.20	1.40
36,000	3.5 to 5.5	X	4.30	4.30	4.60	4.35	4.70	4.90	X	4.60	X	4.85	5.10	5.00	5.05	5.25	5.10	5.30	5.55*	5.30	5.56
40,000	8.0 to 10.5	X	9.25	9.30	9.65	9.40	9.45	9.75	X	9.65	X	9.90	10.10	9.95	10.10	10.35	10.25	10.45	10.60*	10.50	10.75*
45,000	13.0 to 16.0	X	14.55	14.60	14.75	14.60	14.65	14.85	X	14.75	X	14.80	15.30	14.95	15.20	15.60	15.25	15.50	15.85	15.60	15.85
50,000	16.0 to 20.0	X	17.80	17.90	18.85	18.85	18.90	19.00	X	18.90	X	18.95	19.20	19.10	19.15	19.60	19.35	19.50	20.00	19.80	19.85

*Out of specification.

G levels for both the functional and endurance levels are based on a test time of one hour in each of the three major axes. The vibration schedule employed was therefore as follows:

Test	Axis	Time (Hrs)	Level (G rms)
Functional	Vertical	1/2	7.7
Endurance	Vertical	1	16.5
Functional	Vertical	1/2	7.7
Functional	Lateral (Side to Side)	1/2	7.7
Endurance	Lateral	1	16.5
Functional	Lateral	1/2	7.7
Functional	Longitudinal (Front to Back)	1/2	7.7
Endurance	Longitudinal	1	16.5
Functional	Longitudinal	1/2	7.7

In preparing this regulator for vibration, a set of outlet pressures was taken as baseline data. Values measured at 15 psig were again low at 36 through 50000 feet. Increasing and decreasing inlet pressure and altitude once again revealed non-repeatability, where deviations of 1.0 to 2.0 inches of water were revealed. In order to prevent erroneous conclusions (drops in outlet pressure due to vibration) an aneroid inspection was made. No new scratches were evident and bleed flow was found normal. The aneroid assembly was reinstalled, and all outlet pressures were found to be within specification at 15 psig with good repeatability (within .5 inches of water) evident. This phenomenon revealed the apparent high sensitivity to correct aneroid placement within its housing. A set of outlet pressures was measured (with a maximum inlet pressure of 60 psig) as baseline data and are considered pre-vibration values.

During functional tests, the regulator was supplied with oxygen at 25 psig, a flow of 10 lpm drawn from the regulator, and outlet pressure (in H_2O) monitored continually (at the outlet of the CRU-60/P connector). Figure 77 shows each of the three vibration axes, based on location in the AV-8A. All testing was conducted with the regulator mounted on a modified East/West bracket (Figure 78) to insure steadiness.

Results of functional testing showed a constant outlet pressure of .85 inch H_2O. A set of outlet pressures at altitude was taken before the start of vibration, and after completion of each axis. −1.0 inch of water tolerance placed on minimum values. Results are presented in Table 32. From this data, drop in outlet pressure can be seen after vibration in the first (vertical) axis, on the order of one inch of water at 15 psig inlet pressure. An outlet pressure check after the second (lateral) axis reveals the same decrease in outlet pressure, with a slight increase in valves measured at 15 psig. All pressures measured at 15 psig are within specification limits after all vibration. No cracks or deformations were evident in the body of the regulator, while slight wear was evident in the bracket slots which mate with the regulator pins.

Noise Level Repeat

Noise level testing was repeated on both regulators – S/N 10E, after acceleration and endurance and S/N 11E, after vibration testing. Results for the standard system and personnel hose assembly are presented in Table 33. Both regulators have again shown excessive dB levels at 6400 Hz with the standard system and, for the first time, excessive levels at 3200 Hz. All values using the personnel hose assembly are within specification, with the large drop in noise level still evident at 5000 and 6400 Hz.

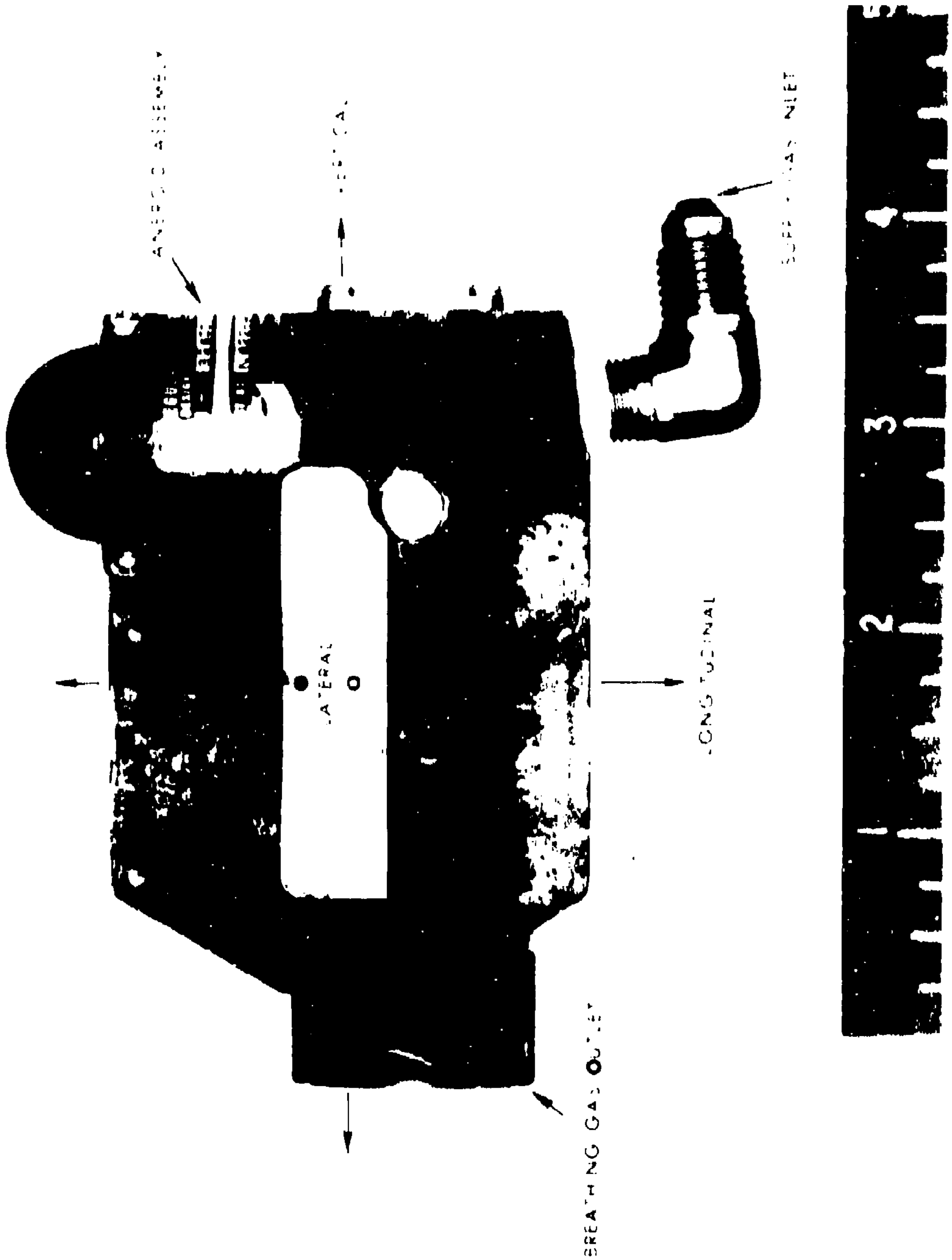


Figure 77 — OEAS Breathing Regulator Axes of Vibration

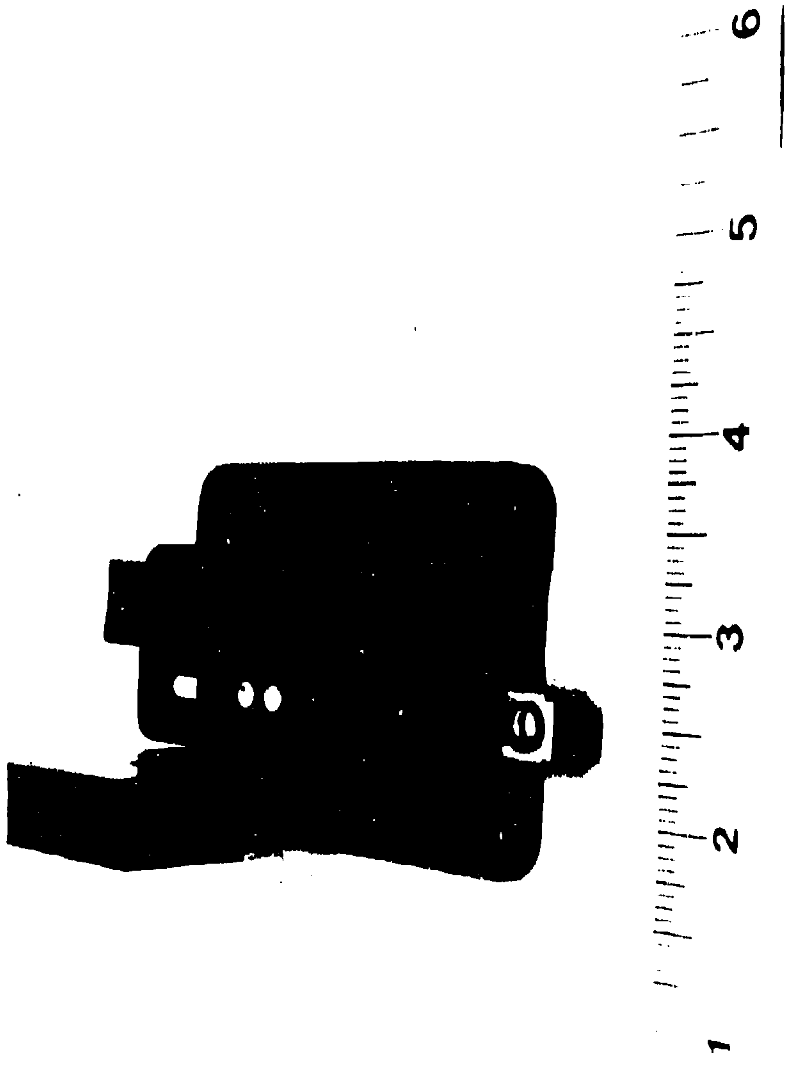


Figure 78 — Modified Breathing Regulator Mounting Bracket

Table 32

OEAS BREATHING REGULATOR VIBRATION OUTLET PRESSURES

Test Altitude In Feet	Spec. Limit (Inches of Water)	Inlet Pressure											
		5 psig			10 psig		15 psig			25 psig		50 psig	
		0	25	50	0	50	0	70	100	0	100	0	100
Pre Vibration													
Sea Level		1.0	.85	1.0	1.15	.90	X	X	X	1.3	1.3	1 3	1 1
30,000	0 to 1.5	X	X	.95	X	X	1.15	1.0	X	X	X	1.3	1.15
35,000	2.5 to 5.5	X	3.7	X	X	X	3.8	X	4.0	X	X	4.65	4.4
40,000	7.0 to 10.5	X	X	8.2	X	X	9.2	X	8.7	X	X	9.5	9.4
45,000	12.0 to 16.0	X	X	X	X	X	14.2	X	14.05	X	X	14.7	14.5
50,000	15.0 to 20.0	X	X	X	X	X	18.3	X	18.0	X	X	19.0	18.1
Post Vertical Axis													
Sea Level		1.00	0.90	1.25	0.95	1.00	X	X	X	1.00	1.00	1.00	0.80
30,000	0 to 1.5	X	0.95	0.85	X	X	1.10	0.95	X	X	X	1.25	0.95
35,000	2.5 to 2.5	X	2.60	2.65	X	X	3.15	X	2.95	X	X	3.55	3.50
40,000	7.0 to 10.5	X	7.85	7.90	X	X	8.05	X	8.00	X	X	8.85	8.50
45,000	12.0 to 16.0	X	12.70	13.00	X	X	13.50	X	13.25	X	X	13.40	13.60
50,000	15.0 to 20.0	X	17.10	17.35	X	X	17.40	X	17.00	X	X	17.90	17.60
Post Lateral Axis													
Sea Level		1.00	0.90	0.95	0.95	0.75	X	X	X	0.95	0.95	1.05	0.95
30,000	0 to 1.5	X	0.90	0.90	X	X	1.25	0.85	X	X	X	1.30	1.10
35,000	2.5 to 5.5	X	3.25	3.15	X	X	3.35	X	3.25	X	X	4.05	3.85
40,000	7.0 to 10.5	X	6.95	7.40	X	X	8.45	X	8.50	X	X	8.70	9.00
45,000	12.0 to 16.0	X	12.60	13.65	X	X	13.85	X	13.70	X	X	14.05	13.95
50,000	15.0 to 20.0	X	14.90	16.00	X	X	17.45	X	17.65	X	X	18.40	18.10
Post Vibration													
Sea Level		0.90	0.75	1.15	1.15	0.95	X	X	X	1.25	1.00	1.10	1.00
30,000	0 to 1.5	X	0.80	0.90	X	X	1.10	0.75	X	X	X	1.40	1.15
35,000	2.5 to 5.5	X	3.25	3.30	X	X	3.90	X	3.55	X	X	4.20	4.20
40,000	7.0 to 10.5	X	8.40	8.25	X	X	8.50	X	8.15	X	X	8.70	9.00
45,000	12.0 to 16.0	X	12.70	13.00	X	X	13.65	X	13.50	X	X	14.40	14.25
50,000	15.0 to 20.0	X	16.70	16.75	X	X	17.50	X	17.15	X	X	17.85	18.00

Table 33

BREATHING REGULATOR NOISE LEVEL CONTROL TEST (REPEAT) RESULTS

Noise Level (dB)[1]

Freq. (Hz)	Limit (dB)	S/N 80810E				S/N 910011E			
		1	2	3	4	1	2	3	4
320	95	90	91	89	90	88	88	85	86
400	95	90	91	88	89	87	87	84	85
500	95	89	88	87	88	84	84	81	82
640	95	90	90	87	88	84	84	81	83
800	95	85	84	80	82	80	81	77	78
1000	90	78	78	74	74	76	76	73	73
1250	85	76	77	74	73	76	76	73	73
1600	85	85	86	82	82	85	86	81	82
2000	90	87	86	84	84	87	87	83	84
2500	90	87	88	83	83	88	89	83	83
3200	85	89[2]	89[2]	84	84	90[2]	89[2]	84	84
4000	90	80	81	75	75	82	82	75	75
5000	85	79	82	71	70	83	79	70	70
6400	85	91[2]	95[2]	75	75	92[2]	96[2]	77	77

[1]Tolerance ± 2 dB

Test Condition 1 – 25 psig, Standard System
2 – 120 psig, Standard System
3 – 25 psig, Personnel Hose Assembly
4 – 120 psig, Personnel Hose Assembly

[2]Out of Specification

Underwater Breathing

Underwater breathing was conducted on one regulator (S/N 11E) in accordance with MIL-R-81553 in its chest mounted configuration (hard hose, A-13A mask). The personnel hose assembly was not employed as there will never be a need for the regulator, in its aircraft mounted configuration, to operate while submerged (an aircraft ditch will preclude OEAS operation and breathing gas to the primary regulator).

The regulator showed satisfactory operation while at a depth of 16 feet in both upright and inverted positions, although some difficulty in exhalation was evident. The regulator (as expected) showed erratic operation after the exposure.

Summary

Results for the Breathing Regulator testing program can be summarized as follows, with the tests for each regulator presented in chronological order:

Outlet Pressure (Initial)

S/N 10E – Within specification limits with 15 psig, above specification maximum with 120 psig inlet pressure.

S/N 11E – Within specification limits with 120 psig, below specification minimum with 15 psig inlet pressure. Non-repeatability (deviations of up to 1.0 inches of water) evident.

Demand Valve Leakage (S/N 10E, 11E)

No change in outlet (safety) pressure after 5 minute period.

Body Leakage (bleed flow)

S/N 10E – 450 cc/min; S/N 11E – 250 cc/min.

Noise Level (S/N 10E, 11E)

Above specification values for both regulators at 6400 Hz in chest mounted configuration. In specification for both regulators utilizing the personnel hose assembly.

Overload (Inlet and Outlet) (S/N 10E, 11E)

Results satisfactory.

Post Overload

Shift in outlet pressure from values measured initially.

S/N 10E – Within specification with 5 psig, above specification maximum with 120 psig inlet pressure.

S/N 11E – Within specification at all inlet pressures (5 to 120 psig).

High Temperature (Outlet Pressure)

S/N 10E – Within specification values measured with inlet pressures of 15 to 120 psig with tolerance of ± 1.0 inches of water added to outlet pressure limits.

S/N 11E – Within specification values measured with inlet pressures of 15 to 120 with no tolerances added.

Post High Temperature

S/N 10E – Outlet pressures within specification at 15 psig, above specification maximum with 120 psig inlet pressure; Bleed Flow – 540 cc/min; Demand Valve Leakage – increase of .15 inches of water with 120 psig inlet pressure.

S/N 11E – In specification with 120 psig, below specification minimum (at 36,000 feet) with 15 psig inlet pressure; Bleed Flow – 385 cc/min; Demand Valve Leakage – increase in .10 inches of water with 120 psig inlet pressure.

Low Temperature (Outlet Pressure)

S/N 10E – Outlet pressures in specification with 15 psig inlet pressure with no tolerances added. In specification values with 120 psig inlet pressure with 1.0 inch of water added to maximum limit.

S/N 11E – Outlet pressures in specification at 15 psig inlet pressure with 1.0 inch of water tolerance placed on minimum limit. In specification with 120 psig inlet pressure with no tolerance added.

Post Low Temperature

S/N 10E – Outlet pressures within specification at 15 psig, above specification maximum with 120 psig inlet pressure; Bleed Flow – 450 cc/min; Demand Valve Leakage – increase of .10 inch of water with 5 psig, decrease of .30 inches of water with 120 psig inlet pressure.

S/N 11E – Outlet pressures below minimum with 15 psig, within specification with 120 psig inlet pressure; Bleed Flow – 175 cc/min; 100 cc/min after 4 day storage; Demand Valve Leakage – increases of .10 and .20 inches of water with inlet pressures of 5 and 120 psig respectively.

Regulator returned to vendor.

High Temperature (Repeat) (S/N 11E)

Outlet pressures in specification with inlet pressures of 5 and 15 psig with no tolerances added. Within specification with 120 psig and 1.0 inch of water tolerance added to maximum limit.

Post High Temperature (Repeat) (S/N 11E)

Outlet pressures within specification with inlet pressures of 5 and 15 psig, above specification maximum with 120 psig; Bleed Flow – 390 cc/min.

Low Temperature (Repeat) (S/N 11E)

Outlet pressure within specification with inlet pressures of 5 and 15 psig with no tolerances added. Out of specification with 120 psig.

Post Low Temperature (Repeat) (S/N 11E)

Outlet pressure below specification minimum with 5 psig at 50,000 feet, within specification with 15 psig, and above specification with 120 psig inlet pressure; Bleed Flow – 400 cc/min.

Acceleration (S/N 10E)

Satisfactory results during acceleration. With post acceleration outlet pressure test, decline in values with 5 and 15 psig, within specification with 120 psig inlet pressure; Bleed Flow – 440 cc/min.

Endurance (S/N 10E)

Drop in outlet pressure with low inlet pressure evident with mid and post endurance tests; Bleed Flow – 500 cc/min; Demand Valve Leakage satisfactory.

Regulator returned to vendor after further drop in outlet pressure after one week of storage.

Acceleration (Second Attempt) (S/N 10E)

With the aneroid assembly recalibrated, acceleration repeated. Although results during acceleration were satisfactory, large decline in outlet pressure evident with post test check. Below minimum values measured with 70 psig.

Regulator returned to vendor.

Acceleration (Third Attempt) (S/N 10E)

Satisfactory results during acceleration. No decline in outlet pressure with post test check, with values at 90 psig above specification maximum.

Endurance (Repeat) (S/N 10E)

Within specification values with post endurance outlet pressure check with 5 psig, some values above maximum limit with 90 psig inlet pressure; Bleed Flow – 540 cc/min; no demand valve leakage.

Vibration (S/N 11E)

Prior to test initiation, aneroid assembly removed and cleaned due to non-repeatability at altitude. Test successful with outlet pressure test after each axis with tolerances of ± 1.0 inch of water added to specification limits.

Noise Level Repeat (S/N 10E, 11E)

Above specification levels for both regulators at 3200 and 6400 Hz in chest mounted configuration. In specification for both regulators utilizing personnel hose assembly.

Underwater Breathing (S/N 11E)

Results satisfactory with chest mounted configuration utilized.

PERFORMANCE MONITOR

Results for the OEAS Performance Monitor developmental test program are as follows, based on the data presented in reference 24.

Individual Tests

The following are individual tests conducted to verify normal performance as acceptance tests and as a means of evaluating the effects of environmental stress testing.

Operation at Sea Level and Press-to-Vent – With 100% oxygen supplied at 25 psig, the monitor output (digital voltmeter) reading shall be between 2.85 and 3.00 volts at sea level after a warm up time of 15 minutes. This corresponds to a measure of partial pressure through a conversion factor of approximately 3.9 millivolts/millimeter of mercury (example: 2950 mv/3.9 mv/mm Hg = 756 mm Hg). Any calibration/adjustment is made with the gain potentiometer.

With 100% oxygen supplied at 7 psig, the press-to-vent button is depressed and the warning light is activated within a period of 20 seconds. The warning light on occurs at 220 ± 10 mm Hg (0.858 mv or 29% oxygen at sea level). Some hysterisis is evident with the warning off point, which is limited to a maximum of 20 mm Hg higher than the activation point (0.936 mv or 31.7% oxygen).

Inlet Gas Supply – With a pressure of 4 psig applied to the inlet of the performance monitor, sample gas flowrate is a minimum of 0.2 lpm. With inlet pressures of 25 and 70 psig, sample flowrates are approximately 1.0 lpm and 2.0 lpm, respectively.

Operation at Altitude – Operational tests are conducted at 10,000, 20,000, 30,000, 40,000 and 50,000 feet in order to verify performance in accordance with Figure 17.

Leakage – With 5 psig applied to the inlet and the altitude compensation valve sealed, monitor leakage will not exceed 10 cc/min.

Overpressure

The performance monitor shall be capable of withstanding an internal pressure of 75 psig with no damage.

Operation at Altitude

The performance monitor was subjected to altitude testing at standard temperature in order to check warning activation points at 10, 20, 30, 40 and 50,000 feet. The minimum (210 mm Hg) and maximum (230 mm Hg) warning activation points are presented in Table 34 and Figure 79. Maximum deactivation (after warning light activation) values are also presented. Due to sensor hysterisis, this value can reach a maximum of 250 mm Hg (20 mm Hg above warning). With warning activation at 230 mm Hg at 28,000 feet or above, warning deactivation is impossible if maximum hysterisis limits are exhibited. These values also show that, due to a maximum of 95% oxygen from the molecular sieve concentrator, warning activation must occur at a maximum level of 86.9% oxygen (214.6 mm Hg) for warning deactivation capability at 28,000 feet or above with maximum hysterisis. If warning activation occurs at 93.1% oxygen, any hysterisis in deactivation cannot exceed 4.6 mm Hg.

The performance monitor (S/N 009E) showed satisfactory performance with respect to warning activation/deactivation at altitudes up to 30,000 feet. However, while conducting a warning test at 40,000 feet, an output voltage of -4.56 volts was displayed with an input of 100% oxygen. Returning the monitor to sea level showed an output of -2.62 volts. Power supply and set up changes revealed the same result. An operational check approximately 24 hours later again displayed -2.62 volts, although output returned to normal after one hour of operation with 28 VDC and 100% oxygen supplied at 25 psig. The monitor was returned to 40,000 feet for two hours in order to repeat the negative output phenomenon. When normal operation was maintained, the altitude test was repeated, the results of which are presented in Table 35, which includes the results for S/N 010E, successful on its first attempt.

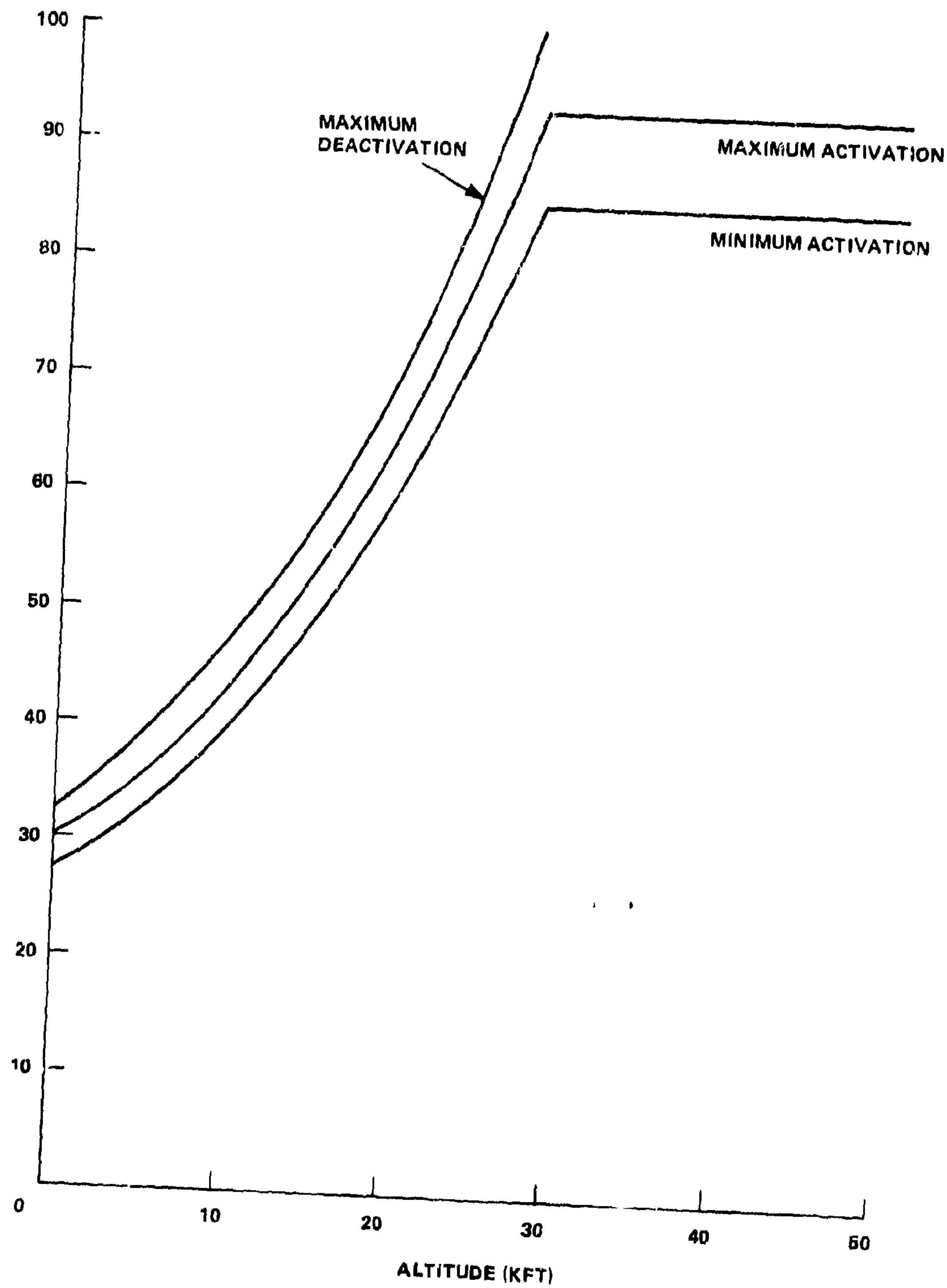


Figure 79 -- OEAS Performance Monitor Warning Activation/Deactivation Limit

Table 34

OEAS PERFORMANCE MONITOR WARNING ACTIVATION/DEACTIVATION LIMITS

Altitude (Feet)	Percent Oxygen		
	Warning Deactivation Minimum[1]	Warning Deactivation Maximum[2]	Warning Deactivation Maximum[3]
Sea Level	27.6	30.3	32.9
10,000	40.2	44.0	47.8
20,000	60.1	65.9	71.6
30,000	85.0	93.1	4
40,000	85.0	93.1	4
50,000	85.0	93.1	4

[1]Equivalent of 210 mm Hg (0.815 volts)

[2]Equivalent of 230 mm Hg (0.892 volts)

[3]250 mm Hg (20 mm Hg above maximum warning)

[4]Warning light activation with 100% oxygen possible

Table 35

OEAS PERFORMANCE MONITOR WARNING ACTIVATION/DEACTIVATION VALUES AT ALTITUDE

Altitude (Feet)	Voltage at 100 Percent Oxygen[1]		Warning On[2]				Warning Off[3]			
			S/N 009E		S/N 010E		S/N 009E		S/N 010E	
	S/N 009E	S/N 010E	Volts	% O_2	Volts	% O_2	Volts	% O_2	Volts	% O_2
Sea Level	2.953	2.960	0.860	29.2	0.876	29.7	0.890	30.2	0.907	30.7
10,000	2.022	2.030	0.875	43.1	0.902	44.5	0.890	43.9	0.906	44.7
20,000	1.356	1.369	0.882	65.1	0.892	65.9	0.895	66.1	0.954	70.4
30,000	0.991	0.950	0.877	91.5	0.847	88.4	0.905	94.4	0.920	96.0
40,000	0.984	0.967	0.870	90.8	0.851	88.8	0.888	92.6	0.928	96.8
50,000	0.996	0.067	0.867	90.5	0.834	87.0	0.919	95.9	0.927	96.7

[1]Limits at sea level 2.85 – 3.00 volts.

[2]Limits 0.815 – 0.892 volts (210 – 230 mm Hg).

[3]Maximum 0.080 volts (20 mm Hg) above on.

Out of specification values were evident with S/N 010E on warning activation at 10,000 feet (232.5 mm Hg) and with excessive hysterisis to warning off at 50,000 feet (24 mm Hg). And, as mentioned previously, both monitors showed a hysterisis excessive enough to exceed the 95% oxygen maximum deliverable by the molecular sieve concentrator.

High Temperature

The performance monitor (S/N 009E) was high temperature tested at an ambient temperature of 160°F. After conditioning for three hours, and while still at 160°F, the monitor was subjected to operation at sea level and press-to-vent tests. Although activating and deactivating the warning light within specification limits and activating the signal in 7 to 8 seconds with a press-to-vent test, a calibration shift was measured with 100% oxygen. The monitor output had climbed to a value of 3.24-3.26 volts (3.00 maximum allowed), after calibration at 2.95 volts. With a return to standard ambient temperature, output again ranged from 3.2 to 3.29 volts with 100% oxygen with a press-to-vent test warning occurring in 26 to 63 seconds. Although the percent oxygen may be slightly out of tolerances at sea level, the variance becomes critical at altitude (e.g., a warning activation of 0.859 volts with a calibration reading of 3.295 volts translates to an activation with 80.2% O_2 at 28,000 feet or above). When it was revealed that the sensor tip delivered had not gone through a routine "bake out" on manufacture (a procedure for high temperature exposure and recalibration to prevent future shifts), the high temperature test was repeated after recalibration to 2.95 volts.

Operational tests at standard temperature after recalibration showed within specification values with respect to warning activation/deactivation, although activation time ranged from 18 to 51 seconds with a press-to-vent test. Operational checks with test repeat at 160°F again revealed excessive voltage with 100% oxygen (approximately 3.1 volts) and warning activation in 4 to 5 seconds. The activation point was also found to be above the maximum allowed (235 mm Hg). Upon return to standard temperature, excessive output voltage was still evident. Warning activation occurred at 22 seconds and was within specified limits. Monitor leakage was found to be zero with sample rates measured as 250 and 750 cc/min with inlet pressures of 4 and 25 psig, respectively. Recalibration to 2.95 volts was again made, with warning activation occurring in 18 seconds and within specified limits.

High temperature testing was repeated as it became evident six hours of sensor "bake out" were not sufficient in preventing a calibration shift (an accurate temperature/time combination could not be supplied by the vendor). Calibration at high temperature had again shifted to slightly higher than 3.0 volts at 160°F in the third attempt, with warning activation in 8 to 10 seconds and within acceptable limits. However, a return to standard temperature revealed a rise to approximately 3.3 volts, with warning activation occurring in 128 seconds. Inlet flows and leakage were again satisfactory. Recalibration was again made with warning activation occurring in 34 seconds.

A fourth three-hour attempt at high temperature was made. The calibration point, however, had shifted downward to 2.81-2.82 volts at 160°F, with warning activation occurring in 13-24 seconds. A return to standard temperature revealed a rise to approximately 3.0 volts, with warning activation unattainable. With air supplied to the monitor at 25 psig, the lowest output voltage attainable was 0.960 volts, which is above the maximum warning activation point (0.892 volts).

The only condition which allowed warning activation was supplying pressurized nitrogen to the monitor. Although the activation point was satisfactory (0.878 volts), the lowest voltage reached was 0.432 volts. A defective sensor was suspected, as maximum voltage was 100% nitrogen is approximately 3 millivolts. Again, warning circuitry appeared satisfactory as activation/deactivation values were within acceptable limits.

The defective sensor was confirmed with return of the unit to the vendor. Previous tip exposure to electromagnetic interference/radiated susceptibility testing (the details of which are presented later in this section) combined with repeated high temperature exposure were the apparent causes for sensor destruction. After radiated susceptibility testing to 50 volts/meter, however, output voltage was found to be 1-2 millivolts with 100% nitrogen. This degradation is also reflected in the excessive times measured for warning activation with a press-to-vent test.

After sensor replacement (a tip already subjected to "bake out"), initial acceptance tests were conducted. Inlet flowrates were found to be 225 and 850 cc/min for inlet pressures of 4 and 25 psig, respectively, and overpressure testing was satisfactory. However monitor leakage was found to be 60 cc/min (10 maximum allowable). Removal of the knurled sensor cover revealed a broken "O" ring, apparently the result of carelessness on assembly. With ring replacement, leakage was found to be zero. A second failure was evident with a press-to-vent test. With the button fully depressed, no change in output voltage was made (no venting). The monitor was returned to the vendor for analysis, where inspection revealed an overtravel of the assembly plunger which eventually "bottomed out" on the electronics module, thus precluding any venting. This phenomenon resulted in a Class I design change, with placement of a washer under the press-to-vent button, preventing overtravel. This anomaly also appears to have had a bearing on previous press-to-vent tests, where varying times to activation were recorded, largely dependent upon how the button was depressed.

High temperature testing was again attempted after all repair. Output voltage (calibration point) rose slightly with warning activation occurring within acceptable limits and under three seconds with a press-to-vent test. Return to standard temperature showed the calibration point slightly above 3.0 volts with warning activation in 13 to 17 seconds and within specification values.

The data which summarizes the events of all high temperature testing is presented in Table 36.

Low Temperature

The performance monitor (S/N 009E) was low temperature tested in accordance with MIL-STD-810C, Method 502.1, Procedure I. However, exposure time was limited to a period of 3 hours and minimum temperature to 40°F. No calibration shift was evident during the 3 hour exposure, with warning signal on/off occurring within specification limits. However, with six press-to-vent tests conducted at 40°F, a lag was evident with warning activation, occurring from a minimum of 36 seconds to a maximum of 57 seconds (20 allowed). With a return to and stabilization at room temperature, the monitor showed correct warning activation with a press-to-vent test and no deviation in calibration point with 100 percent oxygen (2.95 volts).

The monitor was also subjected to a two hour cold soak at -65°F. Supplying power and 100 percent oxygen to the monitor at the end of this period revealed inability of operation, with an output of approximately 90 millivolts (and warning light activation). An additional test was conducted with the monitor operating (100 percent oxygen; 2.95 volts) at standard temperature. Chamber (ambient) temperature was then lowered, with output voltage using as chamber descended below approximately 40°F. Voltage rose to a value of 4.0-4.1 volts, then decreased linearally with temperature, such that a value of 90 millivolts was again read with an ambient temperature of -65°F Low temperature operation has shown an inability to activate the warning light when required with the calibration point rise to 4 volts and has also provided a warning light when not required.

TABLE 36
OEAS PERFORMANCE MONITOR HIGH TEMPERATURE TESTING SUMMARY

Test Condition	Voltage at 100% O_2 [1]	Warning on[2] Voltage	Warning on[2] % O_2	Time[3] (sec)	Warning Off[4] Voltage	Warning Off[4] % O_2
Test 1 - 160° F	3.244 3.264	0.850 9.875	26.2 26.8	8 7	0.907 0.929	28.0 28.4
Post Test 1 (standard temp.)	3.295 3.195 3;205	0.859 0.863 0.864	26.1 27.0 27.0	63 30 26	0.914 0.920 0.901	27.7 28.8 28.1
Pre Test 2 (standard temprecal)	2.945 2.941 2.935 2.940	0.866 0.872 0.872 0.875	29.4 29.6 29.7 29.7	26 51 18 18	0.902 0.942 0.909 0.927	30.6 32.0 31.0 31.4
Test 2 - 160° F	3.091 3.098	0.884 0.912	28.6 29.4	4 5	0.948 0.946	30.7 30.5
Post Test 2	3.112	0.866	27.8	22	0.919	29.5
Pre Test 3	2.945	0.871	29.5	18	0.906	30.7
Test 3 - 160° F	3.030 3.002	0.887 0.883	29.3 29.4	8 10	0.929 0.923	30.7 30.7
Post Test 3	3.279	0.868	26.5	128	0.928	28.3
Pre Test 4	2.945	0.870	29.5	34	0.908	30.8
Test 4 - 160° F	2.812 2.824	0.877 0.879	31.1 31.1	13 24	0.914 0.907	32.5 32.1
Post Test 4	3.004 2.985 (Air) 0.978 (N_2) 0.432	No Warning No Warning No Warning 0.878	 29.3	87 144 - -	- - - -	- - - -
Pre Test 5 (after tip replacement)	2.942 2.954 2.940 2.940	0.878 0.872 0.865 0.876	29.8 29.6 29.3 29.7	18 18 27 20	0.901 0.909 0.926 0.909	30.5 30.8 31.4 30.8
Test 5 - 160° F	2.972	0.845	28.4	3	0.907	30.5
Post Test 5	3.042 3.033	0.878 0.876	28.9 28.9	13 17	0.919 0.901	30.2 29.7

1 - Limits 2.85 - 3.00 volts (2.95 volts nominal)
2 - Limits 0.815 - 0.892 volts/27.6 - 30.3 % oxygen
3 - 20 seconds maximum
4 - Limit 0.080 volts (20 mm Hg) above on

Temperature/Altitude

The performance monitor (S/N 009E) was temperature/altitude tested in accordance with MIL-STD-810C, Method 504.1, Procedure I Equipment Category 5. With minimum temperature held at 40°F, the monitor showed satisfactory performance at altitudes of 10, 20, 30, 40 and 50,000 feet, and satisfactory performance after stabilization at room temperature. The monitor was then exposed to an ambient temperature of 185°F (non-operating) for a period of 16 hours at sea level. An operational attempt was unsuccessful, revealing an output voltage of 0.006 volts when supplied with 100 percent oxygen. Removal and reapplication of power and oxygen showed normal operation although output had dropped to 2.86 volts. Operation remained normal for the next steps, exposure to 131°F and 160°F for four hour and 30 minute periods, respectively. However, the monitor was again non-operational (no voltage output) when exposed to 86°F. When the failure was still evident after a 24 hour stabilization at room temperature, the monitor was returned to the vendor, where a defective lead within the electronics module was repaired and the sensor tip replaced.

Retest of temperature/altitude on monitor S/N 010E again revealed a discrepancy with operation after exposure to 185°F, with an output of 3.5 volts with 100 percent oxygen at sea level. An above maximum voltage output (3.25 to 3.4 volts) remained evident throughout the four sea level conditions. A deficiency was also noted with the press-to-vent button, which showed an inability to return to its normal position after being depressed. Operation improved when the button was removed, lubricated, and reinstalled.

Prior to resumption of the temperature/altitude test (40,000 feet, 116°), the monitor was recalibrated with 100 percent oxygen at sea level to 2.95 volts. After conditioning at 116°F and 40,000 feet, a press-to-vent test did allow the warning light to come on at 0.864 volts, although the light would not extinguish as voltage continued to drop. The monitor was returned to standard temperature and sea level where it showed normal operation. The remaining portions of the temperature/altitude test (50,000 feet, 68°F for 4 hours and 95°F for 30 minutes) were completed with satisfactory results. However, when a retest was attempted at 40,000 feet and 116°F, an intermittent problem was noted. Although warning activation would occur at the correct level, voltage would not always return to a high enough level (hysterisis) to allow the warning light to extinguish. After a return to standard temperature, the monitor showed satisfactory operation at 10,000 foot intervals to 50,000 feet with inlet gas flow and leakage rates satisfactory.

This test has revealed chemical, electronic and mechanical deficiencies as a result of high temperature exposure.

Temperature Shock

The OEAS Performance Monitor (S/N 010E) was temperature shock tested in accordance with MIL-STD-810C, Method 503.1, Procedure I. The monitor (like the oxygen concentrator) was exposed to an ambient temperature of 160°F for 4 hours, followed by 4 hours at -65°F. This sequence was repeated twice for a total of 12 hours at each temperature.

The monitor was allowed to stabilize at room temperature after the 24 hour period. Although a deficiency was evident with the calibration point at sea level (rise to 3.11 from 2.95 volts), no structural damage was evident and the monitor showed normal operation with respect to inlet gas supply, leakage, and press-to-vent operation.

Humidity

The performance monitor was humidity tested in accordance with MIL-STD-810C, Method 507.1. The unit was not operating during this test, with the inlet supply port and power connector capped. The procedure identical to that utilized in concentrator testing was employed (Figure 68).

The unit was checked for operation at test completion with 28 VDC and 100% oxygen. Normal operation with individual tests was evident, although calibration had shifted from 2.95 to 2.50 volts. With a functional check at altitudes of 30,000, 40,000 and 50,000 feet, the monitor output displayed abnormal operation, with a constant decrease in voltage as altitude increased (Table 37). This resulted in an inability to extinguish the warning light at these altitudes with 100% oxygen. For this reason, an aneroid failure (inability to limit the sensor cavity ambient pressure to 28,000 feet) was suspected. An altitude test repeat 48 hours later showed the same result. Aneroid failure was confirmed with disassembly, with heavy corrosion evident. Due to the result of this test, temperature-humidity-altitude testing was not conducted.

Dust (Fine Sand)

The OEAS Performance Monitor was dust tested in accordance with MIL-STD-810C, Method 510.1, Procedure I. The monitor was not operating during the exposure, with sample gas inlet and electrical connector ports capped. The same exposure (particle size, temperature and velocity) and test time as utilized in oxygen concentrator testing was employed.

Functional testing after test completion revealed a failure with operation at altitude, resulting in a warning activation at 34,000 feet with 100 percent oxygen (0.870 volts). Retest approximately 20 hours later revealed improved performance although the warning signal activated at 44,000 feet with 100 percent oxygen. A third operation at altitude test 70 hours after removal from the dust chamber showed normal operation to 50,000 feet (0.950 volts). The entrance of dust into the aneroid assembly appears possible causing seating interference, with eventual dissipation with repeated operation.

Salt Fog

The OEAS Performance Monitor was salt fog tested in accordance with MIL-STD-810C, Method 509.1, Procedure I. The same solution and test time utilized in testing the OEAS Concentrator was employed (Table 10). The monitor also did not operate during the exposure, with gas inlet and electrical connector ports capped.

Functional testing conducted approximately two hours after removal from the salt chamber showed normal operation to an altitude of 50,000 feet. Although a press-to-vent test showed a correct warning activation (0.870 volts) within 20 seconds, the button would not return to its normal (closed) position resulting in constant venting. Subsequent attempts revealed the same anomaly. Corrosion was also evident with the base of the housing of the gain potentiometer and with the four screws which hold the electrical connector in place. Paint blistering was also evident across the top of the electronics module.

Table 37

OEAS PERFORMANCE MONITOR PRE AND POST HUMIDITY CHECKS AT ALTITUDE

	Pre Humidity					Post Humidity				
Altitude (Feet)	Voltage @	Light On[2]		Light Off[3]		Voltage	Light On		Light Off	
	100% O_2[1]	Voltage	O_2%	Voltage	O_2%	100% O_2	Voltage	O_2%	Voltage	O_2%
Sea Level	2.936	0.902	30.6	0.919	31.2	2.517	0.874	29.6	0.921	31.2
10,000	2.124	0.898	44.3	0.840	41.4	1.740	0.882	43.5	0.934	46.1
20,000	1.438	0.894	66.0	0.911	67.3	1.140	0.892	65.8	0.921	68.0
30,000	0.955	0.876	91.4	0.927	96.7	0.734	4	–	5	–
40,000	0.939	0.895	93.4	0.931	97.1	0.444	4	–	5	–
50,000	0.940	0.865	90.3	0.928	96.8	0.364	4	–	5	–

[1]Limits at sea level 2.85 – 3.00 volts

[2]Limits 0.815 – .892 volts (210 – 230 mm Hg)

[3]Maximum .080 volts (20 mm Hg) above on

[4]Light on with 100% O_2

[5]Warning deactivation unattainable

Vibration

The Performance Monitor was vibration tested in accordance with MIL-STD-810C, Category b.2, Procedure IA. The power spectral densities, variable frequency, and overall Grms for the test, based on use for 2000 missions and cabin location, were as follows:

	Functional Test	Endurance Test
G^2/Hz (PSD)	0.04	.2033
Fvar (Hz)	No Inflection	88.6
Grms (G)	7.7	16.5

G levels for both the functional and endurance levels are based on a test time of one hour in each of the three major axes. The vibration schedule employed was therefore identical to that used in regulator testing with respect to test levels and times. The monitor was hard mounted (bolted directly to fixture) for all tests. Vibration axes (based on aircraft mounting) are presented in Figure 80.

During the first half hour of functional testing in each axis, the monitor was supplied with 28 VDC and 100% oxygen at 25 psig (15 minutes) then with air (warning activated) at 25 psig (15 minutes). The second half hour followed the same procedure although the gas was supplied at 5 psig. Output signal (voltmeter reading) was monitored continually. The monitor was non-operating during endurance level testing.

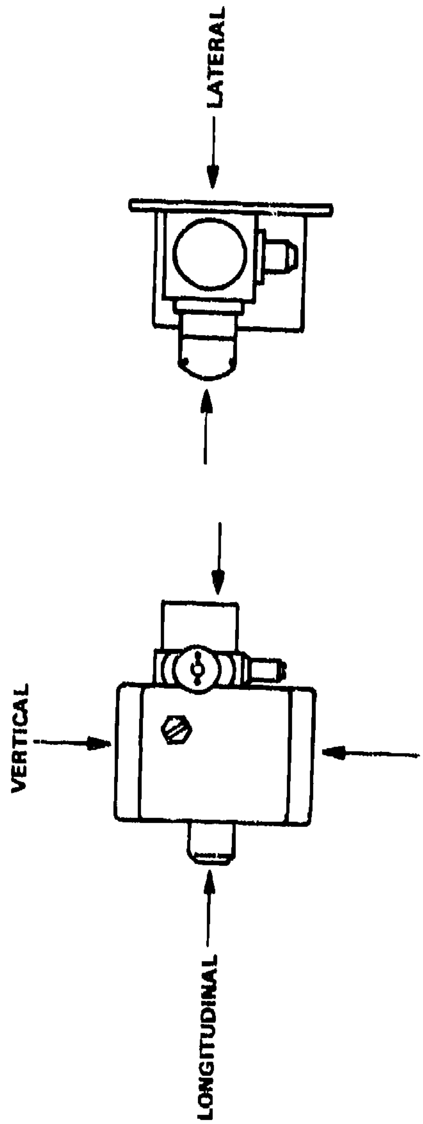


Figure 80 – OEAS Performance Monitor Axes of Vibration

Initial testing was unsuccessful, with a major structural failure evident after 5.5 hours (prior to initiation of last functional test in third axis) of vibration. The block which contains the inlet gas port, sensor housing, and aneroid assembly completely separated from the main body which houses the electronics. Output signal was lost as a result. This failure has been attributed to a quality control deficiency after it became apparent that locking compound was never applied to the four screws which hold this assembly in place.

The second attempt, after monitor repair, resulted in a failure to produce an output signal after 3.5 hours of vibration (prior to initiation of last functional test in second axis). Internal analysis revealed an electronics failure with separation of two capacitors from the electronics card. A mounting plate bracket within the electronics module (a vibration modification) had also broken loose.

With unit repair and placement of RTV on the failed capacitors, the full vibration schedule was successfully completed. The monitor showed no deviation with any individual test conducted after vibration.

Acceleration

The Performance Monitor was acceleration tested in accordance with MIL-STD-810C, Method 513.2, Procedures I and II. The maximum G levels specified (9.0 G operating and 13.5 G non-operating) were employed in each direction due to the possibility of various mounting orientations in future aircraft. The plateau time for each run was one minute. During all operating test runs, the monitor was supplied with 28 VDC and 100% oxygen at 25 psig. Results were satisfactory, with no change in signal output (voltmeter reading) during each run. The monitor showed no structural deformation or deviation with any individual test conducted after nonoperating runs.

Shock

The Performance Monitor was shock tested in accordance with MIL-STD-810C, Method 516.2, Procedure I, Basic Design Test. Three shocks in each direction were applied along three mutually perpendicular axes of the monitor, for a total of 18 shocks. The shock pulse had a peak value of 20G for a nominal duration of 11 ms (Figure 75). The monitor was not operated during the test, but performance checked at its conclusion. Results were satisfactory, with no structural deformation evident and no deviation with any individual test.

Electromagnetic Interference (EMI)

The Performance Monitor was tested for electromagnetic interference/compatibility in accordance with MIL-STD-461A (18) and MIL-STD-462 (19). The appropriate tests specified for Class ID equipment (electrical and electronic equipment and instruments which would affect mission success or safety if degraded or malfunctioned by internally generated interference or susceptibility to external fields and voltages) were conducted.

Within specification values were measured with the following tests:

CONDUCTED EMISSIONS

CE02	0.03 to 20 kHz, Control and Signal Leads
CE04	0.02 to 50 MHz, Control and Signal Leads

CONDUCTED SUSCEPTIBILITY

CS01 0.03 to 50 kHz, Power Leads
CS06 Spike, Power Leads

RADIATED EMISSIONS

RE02 14 kHz to 10 GHz, Electric Field

RADIATED SUSCEPTIBILITY

RS01 0.03 to 30 kHz, Magnetic Field
RS02 Magnetic Induction Field

Out of the specification values/monitor malfunctions were observed with the following tests:

CONDUCTED EMISSIONS (CE01) 0.03 to 20 kHz, Power Leads

Excessive dB levels were measured as presented below, with the warning light activated (monitor supplied with 21% oxygen). All other observed emissions met specification requirements.

28 VDC (PIN B)	28 VDC RETURN (PIN D)	SPEC LIMIT
120 dB	104 dB	90 dB

CONDUCTED EMISSIONS (CE03) 0.02 to 50 MHz, Power Leads

Excessive dB levels were measured as presented in Table 38 in the warning light on mode. All other observed emissions met specification requirements.

CONDUCTED SUSCEPTIBILITY (CS02) 0.05 to 400 MHz, Power Leads

A failure was evident in the warning light on mode on PIN D at frequencies of 3.24-4.10 MHz and 1 VDC. The threshold level at these frequencies has been determined to be 0.8 VDC.

RADIATED SUSCEPTIBILITY (RS03) 14 kHz to 10 GHz, Electric Field 200 Volts/meter

Subjecting the monitor to 200 volts/meter (for equipment external to the aircraft, as cabin mounted are considered) caused complete sensor destruction which, along with an internal electronics failure, resulted in an inability of the performance monitor to display an accurate output and complete inability to activate the warning light. After electronics repair and sensor replacement, RS03 was conducted with the intent of determination of threshold values for field intensity. Threshold values are those maximum intensity levels which do not cause a failure, i.e., activate the warning light when supplied with 100% oxygen or to deactivate the warning light when supplied with 21% oxygen. Intensity was limited to a maximum of 50 volts/meter. These values are presented in Table 39.

Table 38

PERFORMANCE MONITOR CONDUCTED EMISSIONS (CE03)
EXCESSIVE dB LEVELS

Frequency (MHz)	Pin B (dB)	Pin D (dB)	Spec Limit (dB)
.020	73.0	85.0	50.0
.022	70.1	82.1	49.1
.028	64.2	74.2	47.7
.034	62.6	66.6	46.4
.045	62.1	62.1	44.7
.055	58.5	58.5	43.3
.065	50.0	51.0	42.2
.075	45.0	46.0	41.2
.080	44.3	41.3	41.0

SYSTEM ACCESSORIES

Restraint and Life Support Assembly

The modified Restraint and Life Support Assembly (RALSA), Model No. SEU-3/A (Figure 23) was random vibration tested in accordance with MIL-STD-810C, Equipment Category b.2, Procedure IA. The same vibration envelope as utilized in breathing regulator and performance monitor testing (due to cockpit location) was employed. During all functional level testing (7.7 Grms) the emergency cylinder was activated, supplying 60 psig to the emergency regulator inlet. A set flow of 10 lpm was drawn from the regulator with outlet pressure (in H_2O) monitored continuously. During all endurance level (16.5 Grms) testing, the breathing gas cylinder was filled with nitrogen at 1800 psig without supply gas to the regulator (system deactivated).

Results for all functional level testing were satisfactory, showing a positive pressure of approximately 2.5 inches of water delivered at all times. However, the first hour of endurance level testing (longitudinal (front to back) axis) produced a leak in the bourdon tube of the one inch diameter supply pressure gage, resulting in complete system gas depletion. This gage was removed and replaced with a pipe plug, resulting in satisfactory operation throughout the remainder of the test schedule. The regulator showed no evidence of structural deformation at the conclusion of the test.

The emergency breathing regulator had also been functionally tested by the Naval Air Test Center, with satisfactory operation evident at altitude and during underwater breathing.

Personnel Hose Assembly

The Personnel Hose Assembly was windblast tested by Dayton T. Brown, Inc., under NAVAIRDEVCEN Contract N62269-80-G-0212 (30) in order to insure the assembly will remain intact, providing emergency oxygen, after an ejection. Various post ejection testing attitudes, manakin sizes and mounting configurations were employed, each of which is presented in Table 40. Velocities shown were maximum peaks, with a test duration of 3 seconds nominal. A photograph of the mounting configuration in the Stencel Aero Engineering Corporation SEU-3/A ejection seat for windblast test number 1A is presented in Figure 81.

Table 39

PERFORMANCE MONITOR RADIATED SUSCEPTIBILITY (RS03)
THRESHOLD LEVELS

MODE 1 - Light On (21% Oxygen)

Frequency	Threshold (V/M)	Frequency	Threshold (V/M)
.014 - 1.3 MHZ	50.0	6.1 - 158	50.0
1.3 - 1.6	30.0	159 - 161	35.0
1.6 - 4.3	18.5	161.0	10.0
4.3 - 5.0	30.0	161.3	17.0
5.0 - 5.8	20.0	162 - 1000	50.0
5.8	15.5	1 - 10 GHZ	50.0
5.8 - 6.0	20.0		

MODE 2 - Light Off (100% Oxygen)

Frequency	Threshold (V/M)	Frequency	Threshold (V/M)
		(Vertical)	
.014 - 1.2 MHZ	50.0	210 - 270	50.0
1.21	45.0	270 - 355	25.0
1.27	30.0	355	20.0
1.46	10.0	355 - 400	50.0
1.96	2.0	400 - 410	20.0
4.15	3.0	410 - 640	50.0
5.31	2.0	640	30.0
6.05	35.0	641 - 1000	50.0
6.06 - 8.2	50.0	1 - 10 GHZ	50.0
8.23	25.0	(Horizontal)	
10.09 - 21.0	50.0	210 - 230	50.0
37 - 40	20.0	230 - 235	20.0
40 - 60	50.0	235 - 245	50.0
60 - 63	20.0	245 - 260	20.0
63.3	15.0	260 - 265	50.0
118	5.0	265 - 280	20.0
177	35.0	280 - 385	50.0
195	5.0	385 - 460	20.0
210	35.0	460 - 580	50.0
		580 - 590	30.0
		590 - 1000	50.0
		1.0 - 1.42 GHZ	50.0
		1.42 - 1.7	20.0
		1.7 - 10.0	50.0

Figure 81 – Personnel Hose Assembly Windblast Test Number One Configuration

Table 40

WINDBLAST TEST RUNS

Number	Fixed Test Attitude	Velocity KEAS	Manakin Size	CRU-60/P Mounting Configuration
1A	Head On	450	95%	MA-2 Torso Harness
1B	45° Pitch Fwd			
1C	45° Pitch Aft			
2A	Head On	450	95%	SV-2 Survival Vest
2B	45° Pitch Fwd			
2C	45° Pitch Aft			
3A	Head On	450	5%	MA-2 Torso Harness
3B	45° Pitch Fwd			
3C	45° Pitch Aft			
4A	Head On	450	5%	SV-2 Survival Vest
4B	45° Pitch Fwd			
4C	45° Pitch Aft			
5A	Head On	660	95%	MA-2 Torso Harness

Results for test number 1B were unsatisfactory, with a separation of the quick disconnect in the hose which connects the seat kit outlet to the CRU-60/P. This test was repeated twice however, with favorable results. Two additional windblast tests were made utilizing a CRU-60/P mounting bracket which was modified by the Naval Air Test Center to insure non-interference with right arm movement. Results were satisfactory with this modified bracket remaining intact on the MA-2 torso harness.

GROUND SUPPORT EQUIPMENT

The Ground Support Equipment (GSE) utilized in organizational and intermediate level testing of the Oxygen Enriched Air System with manufactured by the Bendix Corporation. An equipment description is as follows, based on the details presented in references 25 and 26.

Organizational Level

OEAS Test Set, Part No. 3300148-6101, is designed for organizational level maintenance in the cockpit of the AV-8A aircraft. The test set (17 in. x 11 in. x 8 in.; weight – 20 pounds) contains a pressure gage, performance monitor, percent oxygen meter, pressure regulator, valves, orifices, timer, lamp indicators, test jacks and inlet/outlet connections. The test set will receive the breathing gas produced by the oxygen concentrator, which is then routed to the aircraft performance monitor.

Referring to the test set front panel of Figure 82, the equipment will be used as follows: Breathing gas from the concentrator enters connector J12 (OXY INPUT) with the corresponding pressure read on OEAS pressure gage G10. A sample of this gas is teed to a reference performance monitor (located in the test set) which provides a percent oxygen output indication. The main gas flow is passed through a pressure regulator and controlled with valve V10. The flow selection (high or low) will enable both testing for adequate oxygen concentration and for proper performance monitor warning activation. In the % Oxygen Test Set position, the output signal of the monitor in the test set is displayed on meter M10 as oxygen percent on the right half of the meter. In the % Oxygen Aircraft position, the signal of the aircraft mounted monitor is displayed. Provisions are also included for performance monitor calibration if required, through meter M10, which displays the partial pressure difference between the aircraft mounted monitor and the calibrated monitor within the test set (S10 in Monitor Test function). Calibration is made on the gain potentiometer on the aircraft monitor until meter M10 reads zero.

Intermediate Level

OEAS Concentrator Test Set, Part No. 3300149-6101, is designed for detailed concentrator testing at the intermediate level. The test set (27 in. x 23 in. x 15 in.; weight – 75 pounds) contains pressure and temperature gages, ammeters, oxygen analyzer and indicator, valves, regulators, electronic circuitry, test jacks and inlet/outlet connections. Compressed air is passed through the test set to the oxygen concentrator, with the concentrator enriched air outlet monitored by the test set for various flow rates.

Referring to the test set front panel of Figure 83, the equipment will be used as follows. Shop air supply flows through an inlet filter to air inlet J50. This air flows through adjustable pressure regulator R41 to the concentrator under test, with pressure displayed on gage G41, and temperature on meter TC41. Concentrator enriched air outlet flows through adjustable regulator R42, with pressure displayed on gage G41 (Pressure Select (V42) to Oxy from Conc position) and temperature on TC40. A portion of the concentrator outlet flows through the oxygen analyzer (polarographic partial pressure sensor) with percent oxygen displayed on meter M43. The output of adjustable regulator R42 is measured on gage G42, with outlet flowrate varied through valve V41. The test set is powered by 28 VDC at J41, with a connecting cable placed between J42 and the concentrator under test. Concentrator power consumption is displayed on meters M40 (motor, solenoid and control electronics), M41 and M42 (for each heater).

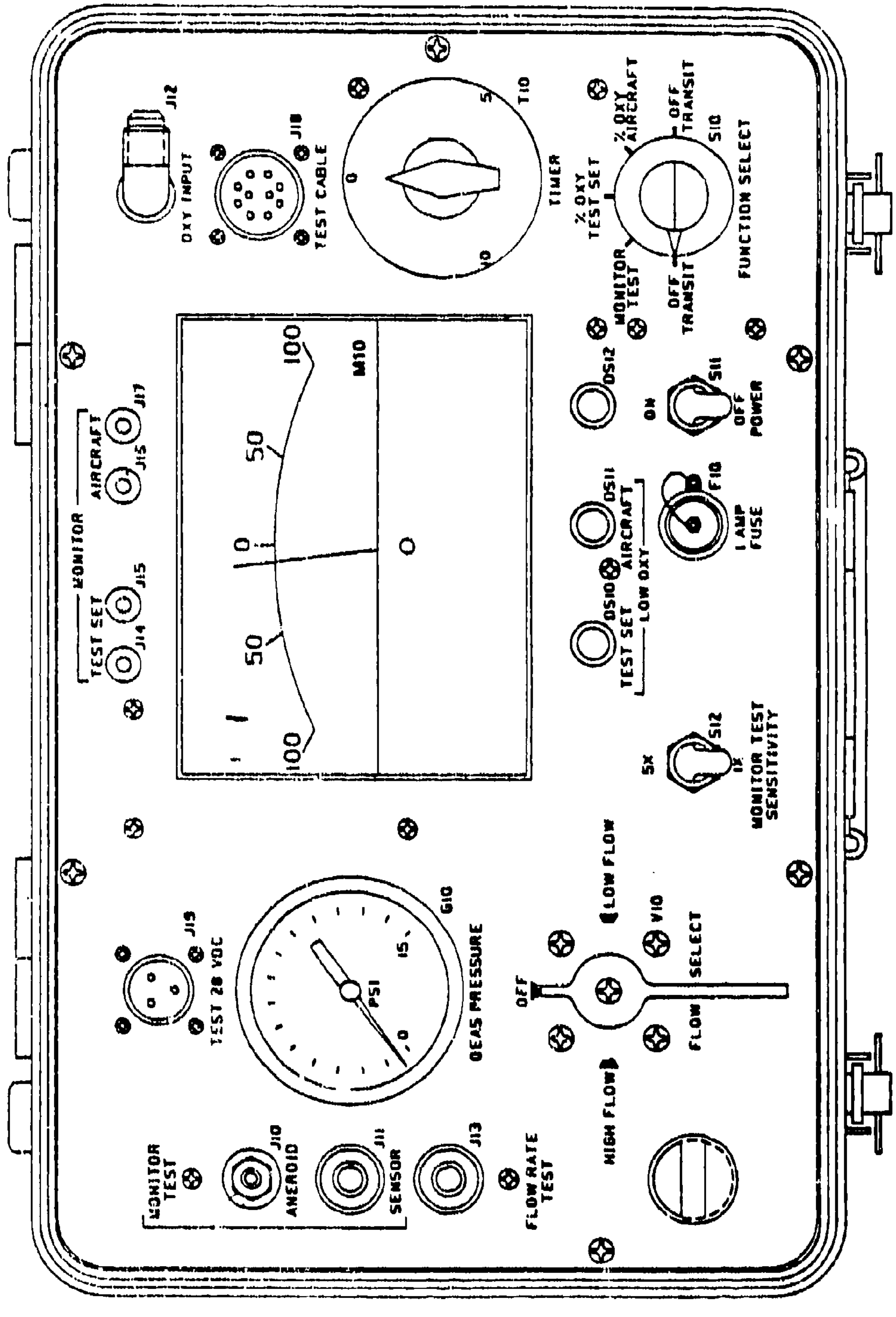


Figure 82 — OEAS Test Set Front Panel

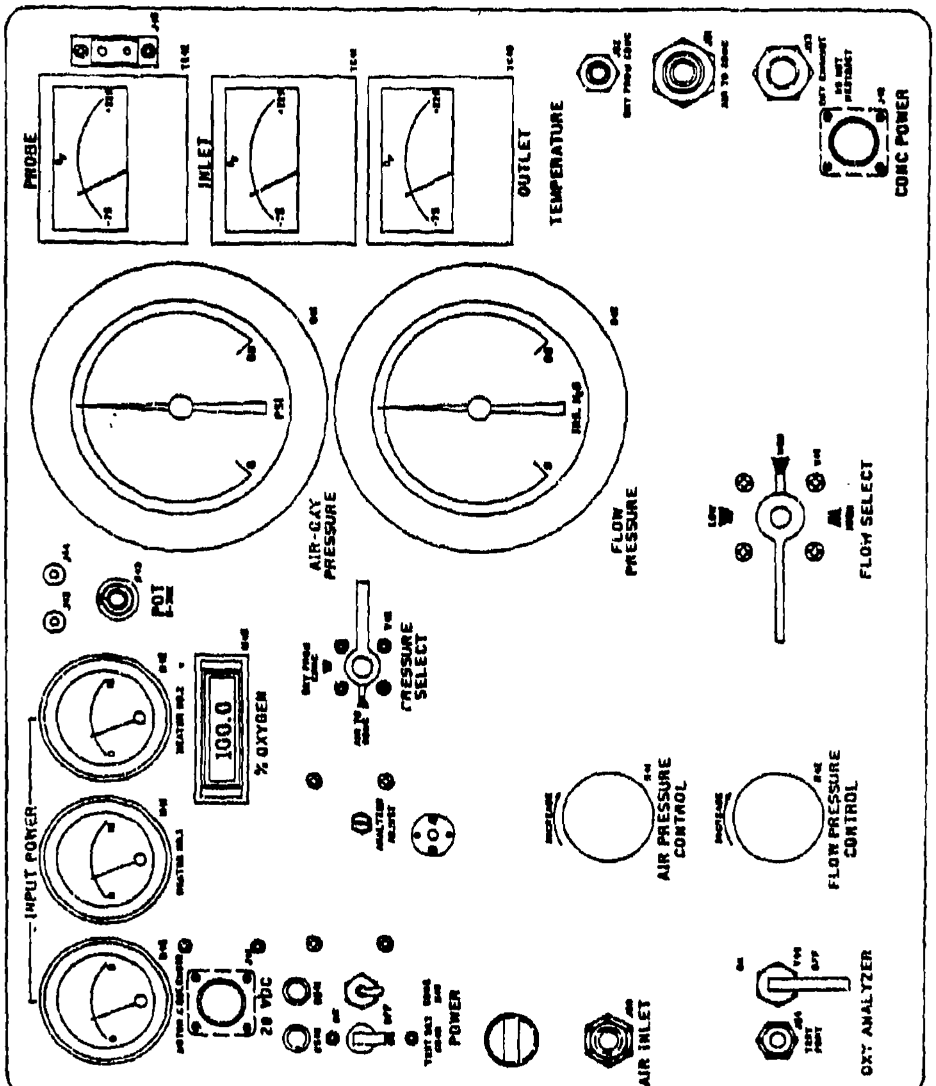


Figure 83 — Concentrator Test Set Panel Layout

Regulator/Monitor Test Set, Part No. 3300150-7001, is designed for intermediate level testing. The test set (27 in. x 23 in. x 15 in.; weight – 70 pounds) contains pressure gages, altitude test chamber (2.5 in. x 6.25 in. x 5.25 in.), valves, switches, timer, lamp indicators, pneumatic and electrical inlet/outlet connections. Referring to the test set front panel (Figure 84), the equipment will be used as follows. The test gas (oxygen for monitor, nitrogen for regulator) is supplied at J24 Test Fluid Inlet, with a pressure regulated by adjustable regulator R20 and read on gage G20. For monitor testing, flow is through valve 22 and out J27 to the monitor under test, with warning light indication on lamp DS21. For breathing regulator testing, flow is through valve 24 to the regulator under test in the test chamber through J28. J23 is provided for connection to Regulator Tester 31TA2655-2, which contains a vacuum source. With the regulator at altitude, outlet pressures are read on gages G22 and G23.

Intermediate level regulator tests can also be conducted utilizing the OTS-565 (outlet pressure only) and 62A test stands, provided a pressure gage displaying an accurate readout in inlet pressure (down to 5 psig) is placed within the altitude chamber of each stand.

RELIABILITY

Although no guidelined reliability program was included within the developmental/qualification testing, the following information is provided as a summary of failures encountered with each component in the program and as a means (through presentation of operating hours and conditions) of assisting with any reliability growth prediction.

The testing program conducted on the oxygen concentrator is essentially broken into two parts: (1) those tests (altitude and temperature) conducted prior to vibration and (2) those conducted after the present, or "final" configuration was attained through vibration modifications. All environmental "stress" tests, along with all operating conditions however, were conducted after the vibration phase of the program to determine what, if any, redesign may be detrimental to other environmental concerns. An approximate breakdown in operating and exposure hours (to date) for the oxygen concentrator is presented in Table 41. Transient times are also included in the summary, such as the times required for chamber standard (room) temperature to -65°F, or for heating of high temperature air.

Pre-qualification testing of the OEAS Breathing Regulator and Performance Monitor involved functional checks at altitude only (for outlet pressure and warning activation). Again, all of the conditions presented in Tables 42 and 43 were conducted with the units in their "final" configuration, that is, after vibration modifications and use with the Personnel Hose Assembly were determined necessary when the regulator became air frame mounted, and after vibration modifications and a press-to-test feature were incorporated into the monitor.

The failures encountered in the program whether through quality control, design, or state-of-the-art deficiencies, are presented in Tables 44, 45, and 46 for the concentrator, regulator, and monitor, respectively. Again, all of the failures presented are with present/final configurations.

A strictly controlled reliability program will be conducted on the Oxygen Concentrator, and on improved versions of the Breathing Regulator and Performance Monitor (Appendices B and C) by the Naval Weapons Support Center, Crane, Indiana, under NAVAIRDEVCEN Work Request N62269/81/WR/00812.

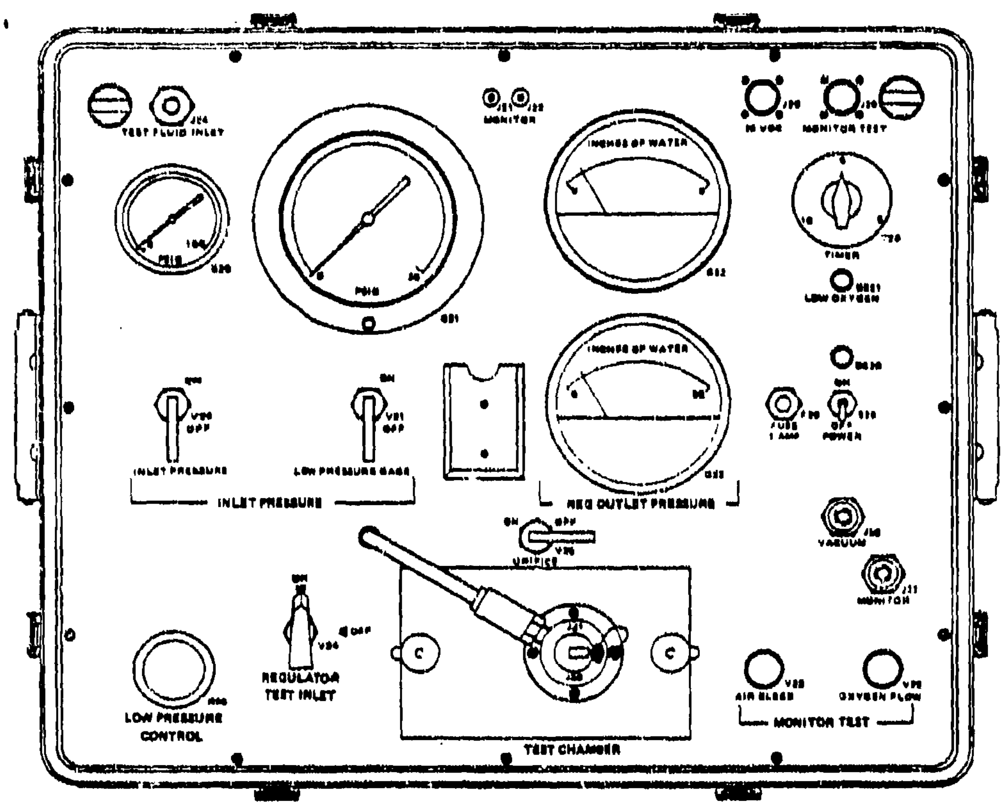


Figure 84 – Regulator Monitor Test Set Panel Layout Part No. 3300150-7001

Table 41

OEAS CONCENTRATOR ENVIRONMENTAL CONDITIONS

Environmental Condition	Operating (Hours)		Non-Operating (Hours)	
	Developmental	Final	Developmental	Final
Standard Temp Ambient/Inlet Air				
– Sea Level	80	50	N/A	N/A
– Altitude	170	250	N/A	N/A
High Temperature				
– Ambient	N/A	N/A	36	120
– Ambient/Inlet Air	40	60	N/A	N/A
High Temperature Inlet Air/Altitude	0	60	N/A	N/A
Low Temperature				
– Ambient	N/A	N/A	16	90
– Ambient/Inlet Air	68	42	N/A	N/A
Vibration	4.5	1.5	30	18
Humidity				
– Standard Temp	N/A	N/A	0	180
– High Temp	N/A	N/A	0	140
Dust				
– Standard Temp	N/A	N/A	0	12
– High Temp	N/A	N/A	0	16
Salt Spray	N/A	N/A	0	98

N/A – Not Applicable

Although considered initially, the reliability strategy of MIL-STD-781C (21) will not be utilized due to the high number of test hours involved (in order to achieve the design goal of 2,000, 2,800 and 2,800 hours Mean-Time-Between-Failure (MTBF) for the concentrator, regulator and monitor) and high probability of non-success. The strategy to be employed, under the guidance of AIR-51851D and NAVAIRDEVCEN's Reliability and Maintainability Branch of the Systems Readiness Division, Systems Directorate, utilizes a reliability growth curve/prediction. The method, a TAAF (Test, Analyze and Fix) regime allows for failures during the program, analyzation and repair, with test continuation of the failed item.

Table 42

OEAS BREATHING REGULATOR ENVIRONMENTAL CONDITIONS

Environmental Condition	Operating Hours	Environmental Condition	Operating Hours
Safety Pressure (Sea Level to 30,000 feet)	20	Low Ambient Temp/ Safety Pressure	14
Pressure Breathing (36 to 50,000 feet)	14	Low Ambient Temp/ Pressure Breathing	3
High Ambient Temp/ Safety Pressure	14	Endurance	200
High Ambient Temp/ Pressure Breathing	3	Vibration*	6

*Includes 3 hours of endurance (non-operating) level

Table 43

OEAS PERFORMANCE MONITOR ENVIRONMENTAL CONDITIONS

Environmental Condition	Operating Hours	Non-Operating Hours	Environmental Condition	Operating Hours	Non-Operating Hours
Standard					
Temp			Vibration	7	8
Sea Level	50	N/A			
Altitude	30	N/A			
			Humidity		
High Ambient			Standard Temp	N/A	160
Temperature			High Temp	N/A	80
Sea Level	32	50			
Altitude	12	N/A	Dust		
			Standard Temp	N/A	12
Low Ambient			High Temp	N/A	16
Temperature					
Sea Level	12	20	EMI	80	N/A
Altitude	10	N/A			

Table 44

OEAS CONCENTRATOR FAILURE ANALYSIS SUMMARY

Failure	Cause	Remedy
Unit motor inoperative on initial start up when received	Interference of a lead wire in the electronics box with one bottom mounting screw, resulting in a short to chassis	– Wire rerouting – Insulation to mounting screws – Added acceptance test
Outlet pressure 3 psig higher then expected when tested with inlet pressures of 45 and 60 psig	Lubrication not applied to piston on internal reducer, resulting in setting shift	Quality control improvements on assembly
Outlet pressure 3 psig higher than expected when tested with inlet pressures of 45 and 60 psig	Lubrication dissipation from piston of internal reducer	Lubrication added; design improvements needed
Unit motor inability for repeated start up after temp/hum/alt test	Broken lead/diode at epoxy RTV interface within electronics box; temp cycling suspected	Solder joint repair; design improvements needed
High noise level evident with motor start up	Lubrication dissipation in gear head assembly; high temperature inlet air suspected	Assembly replaced; design improvements needed
Various warning activations with high temperature inlet air at altitude	Reductions in inlet air flowrate, limiting concentration capabilities	Limit temperature and/or pressure from aircraft at altitude
Oxygen concentrations measured below minimums acceptable	Particulate matter within cartridge, restricting bed inlet pressure	Replace cartridge, add filter in house air line
Continuous activation of heater No. 1, above normal bed inlet temperature	Defective transistor after salt spray exposure	Transistor replaced; design improvements needed

Table 45

OEAS BREATHING REGULATOR FAILURE ANALYSIS SUMMARY

Failure	Cause	Remedy
Outlet pressures higher than maximum allowed with 120 psig inlet pressure	For use with AV-8A OBOGS only	Redesign for LOX system compatibility necessary
Excessive noise level at 6400 Hz in chest mounted configuration	Filter design deficiency	Redesign noise suppression filter or raise specification limit
Rise in outlet (safety) pressure with no flow	Demand valve leakage	Design improvement needed
Non-repeatable outlet pressure testing	Scratches in aneroid seat	Improved quality control with assembly
Drop in outlet pressure after acceleration, endurance, and storage	Aneroid calibration shift	Design improvement to hold calibration needed
Excessive noise level at 3200 and 6400 Hz in chest mounted configuration after environmental testing	Filter design deficiency	Redesign noise suppression filter or raise specification limit

Table 46

OEAS PERFORMANCE MONITOR FAILURE ANALYSIS SUMMARY

Failure	Cause	Remedy
Electromagnetic Interference CE01, CE03, CS02, RS03	Lack of appropriate filters/casing	Sensor replaced in RS03, design improvements needed
Calibration shift to out of tolerance value after exposure to 160°F	Routine "Bake out" not accomplished after sensor manufacture	Unit recalibrated; quality control improvements
Monitor unable to activate warning light when supplied with pressurized air	Probable previous exposures in radiated susceptibility testing	Sensor tip replaced; design improvements needed

Table 46 – Continued

Failure	Cause	Remedy
Leakage measured as 60 cc/min	Broken "O" ring damaged in vendor assembly	"O" ring replaced; quality control improvements
No change in monitor output with press-to-vent button depressed	Overtravel of button which precludes venting	Design change made to mechanism to prevent overtravel
Calibration shift to out of tolerance values after exposure to ambient temperatures below 40°F	No low temperature compensation with polarographic sensor	Unit recalibrated; no design changes made
Negative voltage display with operation at altitude test at 40,000 feet, standard temperature	Unknown	Restabilization with time, vendor analysis necessary
Sensor housing separation from electronics module in first vibration attempt	Lack of locking compound to four screws which hold this assembly in place	Unit repair with compound applied; quality control improvements
Output signal loss during second vibration attempt	Separation of two capacitors from electronics board	Capacitor repair; RTV compound applied to components
No output voltage at 185°F, after return, lost at 86°F	Inability to withstand exposure to 185°F. Previous vibration may be factor	Design improvements needed
Calibration shift to out of tolerance value and press-to-vent button failure after exposure to 185°F; Failure to extinguish warning at 116°F	Inability to withstand exposure to 185°F	Design improvements needed
Calibration shift to out of tolerance values and failures with operation at altitude after humidity exposure	Corrosion to aneroid/electronics	Design improvements needed

Reliability of the oxygen concentrator will combine environments of ambient temperature, vibration and altitude, although altitude will be simulated by increasing inlet pressure and therefore interior/exterior differential. A total of 1,000 operating hours will be accumulated on four concentrators in accordance with the test cycle of Figure 86. "On" times listed apply to concentrator operation (power and air) as well as vibration. This cycle will be repeated approximately 94 times which translates to the following conditions (with 4 units utilized):

Environment	Condition	Time (Hours)
-65°F	OFF	627
-65°F	ON	345
-65 to 160°F	ON	157
160°F	OFF	627
160°F	ON	345
160 to -65°F	ON	157
	TOTAL ON –	1,004 hours

The vibration will be a functional level (at cruise), the 7.35 Grms level presented in Figure 72.

Critical parameters with respect to normal operation, such as oxygen concentration, outlet pressure and power consumptions will be monitored continually for each unit during all "on" periods. Provisions are included for raising inlet air pressure to values expected with removal of the bleed air regulator and for inlet air temperature to values measured on the AV-8A. These values will be utilized in two cycles for each unit. In addition, for simulation of changes in ambient temperature with storage (non-operating), "on" periods shall become "off", with "off" periods becoming "on". Again, this test shall be accomplished for two cycles for each unit.

The reliability program for the regulator and monitor combines environments of ambient temperature and altitude, with vibration imposed separately. The reliability test cycle of Figure 85 will also be employed with an altitude of 25,000 feet attained during "on" portions. Once every four cycles the units will be subjected to an altitude of 50,000 feet (during the "on" portion of the "D" segment of the test cycle).

A total of 1,000 operating hours each will be accumulated on six regulators and on six monitors. "On" times apply to regulator operation when supplied with nitrogen and to monitor operation when supplied with oxygen and 28 VDC. Approximately 63 test cycles will be conducted. Parameters necessary to insure normal operation such as regulator outlet pressure and monitor output signal and power consumption will be continually monitored and periodically recorded. Provisions are again included for testing with inlet pressures anticipated with bleed air regulator removal and for reversal of "on/off" times. The vibration portion of the program (conducted separately) will consist of a low level random envelope (2.07 Grms) based on cockpit location. All twelve units will be vibrated again mounting to 1,000 hours each for the regulator and monitor.

A Failure, Reporting, Analysis, and Corrective Action (FRACA) cycle, along with a Failure Analysis Board (FAB) have been established to insure detailed reporting as to the cause of any failure and the action taken to correct it.

This program will provide a means of determination not only of those deficiencies which did not surface during the developmental/qualification program, but an accurate prediction of the apparent drops in oxygen concentration with time and of polarographic sensor tip life.

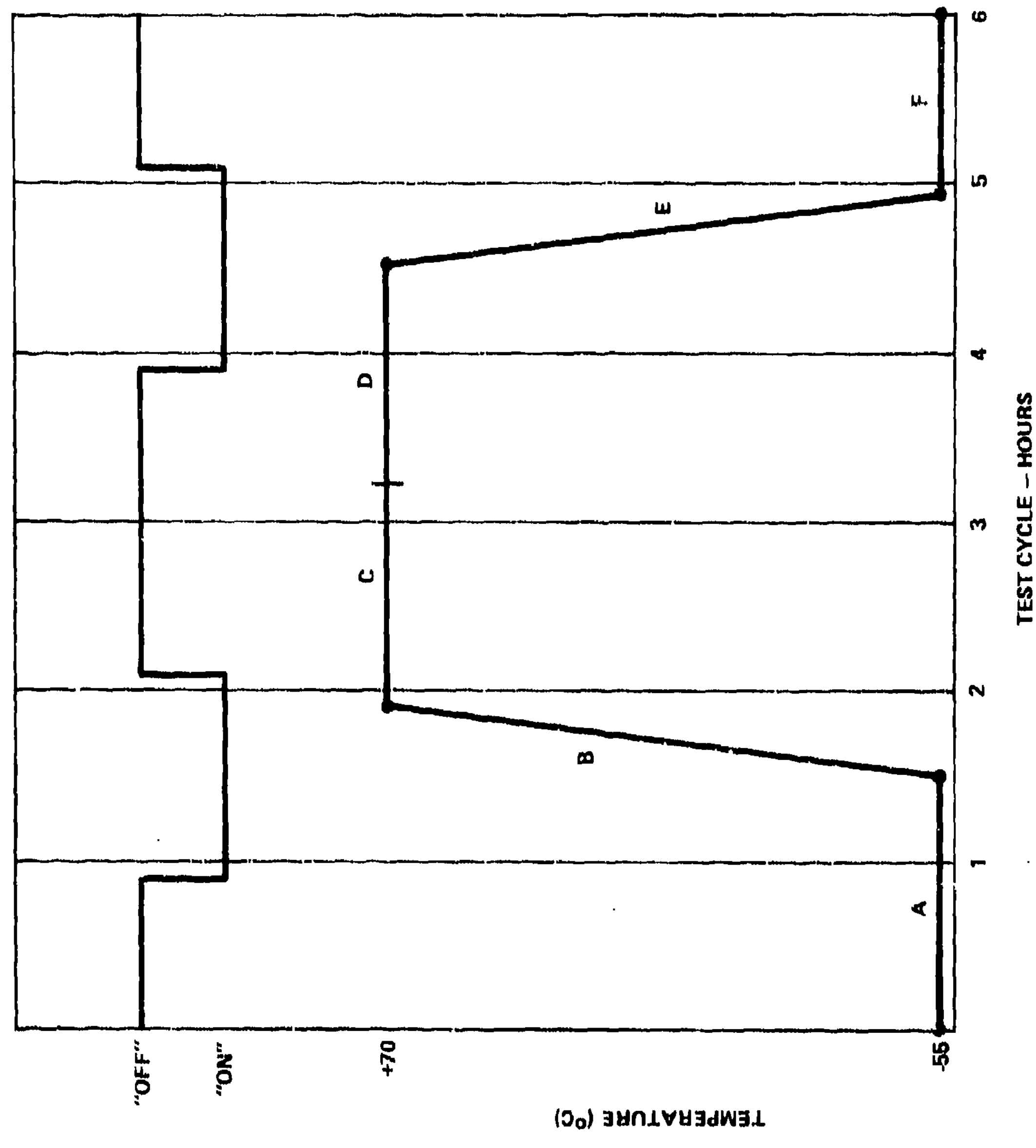


Figure 85 — Reliability Test Cycle Profile

CONCLUSIONS AND RECOMMENDATIONS

Oxygen Concentrator

The Oxygen Enriched Air System (OEAS) Oxygen Concentrator has demonstrated the ability to provide a sufficient quality and quantity breathing gas for a one man open loop breathing schedule. Concentrations delivered for a two man breathing rate are, in most cases, higher than those delivered for one due to reductions in argon delivered. In addition, the incorporation of the F version of MIL-D-19326 (12), which places correction factors on (and therefore raises) the breathing rates for one man will also show higher oxygen purities at altitude. The actual breathing waveform may also result in higher purity, with a peak value of approximately pi times the steady state flows measured in this program. Acceptable oxygen concentrations were also found with the bleed air supply pressures anticipated on board the AV-8A. The increasing of inlet pressure above 28 psig has negligible effect on oxygen purity at altitude.

The oxygen concentrator, as anticipated, has shown performance degradation with high or low temperature extremes, with time becoming the critical factor. The higher inlet air temperatures anticipated at sea level will not pose a problem with respect to purity due to (1) the duration required for a significant drop and limitations on time at maximum throttle and (2) the large drop required between concentrations initially delivered and that required for warning activation. The limitations on performance at altitude are of greater concern with the need for a high purity breathing gas. Although no degradation will occur with the pressure/temperature limits of the AV-8A, operational limitations with studies of future applications should be considered. In addition, although some conditions for performance drop are not significant in what may be considered a two hour mission, the possibility of extended operational times with in-flight refueling should be realized. Further analysis is required with respect to bleed air temperatures anticipated after extreme low temperature soak. Performance can be improved prior to take-off; (1) increasing inlet air temperature during ascent, (2) bypassing the bleed air heat exchanger at sea level, (3) increasing inlet air pressure or (4) maintaining cabin pressurization. Overall performance, if the heaters are provided with lower voltage also remains an area of concern.

An ideal solution to temperature degradation would be incorporation of a device which allows a "floating" control valve speed and, therefore, a varying cycle time based almost exclusively on ranges of inlet temperature air. Cycle time could be decreased for high temperature and increased for low temperature inlet air. Although detrimental to system simplicity (and therefore reliability), the concept appears worthy of exploration.

The structural integrity of the unit has been demonstrated through acceleration, shock, and vibration testing. The vibration levels from MDC A3780 were selected at a time when it was felt the higher requirements from MIL-STD-810C could not easily be met. Inspection of the difference in vertical level vibration (32.2 vs 24.2 Grms) occurs primarily in the high frequency bandwidth of 1,000-2,000 Hz, which may not contribute significantly to structural degradation. It can therefore be assumed that the oxygen concentrator, in its present configuration, could pass the qualification levels of MIL-STD-810C. The LOX converter mounting tray was not utilized as a fixture in the program. The unit was placed in flat rails and held in place with a bolt/wing nut identical to that employed in the aircraft. This method insured an adequate energy transfer without bolting a fixturing plate directly into the base plate of the unit. Preliminary results of aircraft installation show a high level of vibration reduction between LOX bay and concentrator levels due to tray attenuation. The mounting tray, or equivalent means of vibration isolation should always be used with concentrator installation.

Although providing satisfactory oxygen concentrations throughout the operating envelope of the AV-8A, the following have been determined to be areas for redesign/improvement in an optimized system.

Electronics Module — The electronics module, which continually operates at temperatures well above ambient; thereby decreasing component reliability. With the power inverter believed to be the major source of heat, the direct use of AC power should be considered. Although providing an effective method for withstanding vibration, the use of epoxy/RTV within the electronics module has introduced a problem with respect to wire stress relief resulting in failure for motor start. Size and weight reductions can be made with removal of unnecessary components to simplify circuitry with provisions made for resistance to salt spray, and at that time EMI testing be conducted on the unit.

Pressure Reducer — The pressure reducer, which has exhibited the tendency to shift from initial setting, resulting in higher than normal bed inlet (and therefore outlet) pressures. The problem appears to be with lubricant dissipation occurring with continued operation of inlet pressures above the "kick in" point and possibly accelerated with high temperature inlet air. Although virtually inert in the AV-8A due to incorporation of the bleed line regulator, the utilization in future aircraft should be considered. The rate of increase after initial shift with time and safety considerations should be explored.

Solenoid Casing — Although always capable of correct activation when required, some material change is needed with the solenoid casing (the only component susceptible to humidity) to minimize removal and future operational problems.

Thermal Shroud — Some improvement is needed with shroud ruggedness, as it tears rather easily in normal use. This is detrimental not only to prevention of dust, salt, etc., but to retention of warmup air with low temperature operation.

Motor/Control Valve Coupling — Investigations are required as to the dissipation of gearhead lubricant which can initiate after a short period of time with high temperature inlet air. Continued dissipation will result in failure for control valve turning and no oxygen concentration.

Military specifications (of all components) are now under preparation that will insure fully qualified items with respect to the environmental operating conditions and to all reliability and maintainability requirements.

Based on the data generated for performance in the operating envelope of the AV-8A, it is recommended that Operational Evaluation (OPEVAL) commence. NAVAIRDEVCEN will retain an oxygen concentrator and test equipment in order to attempt to analyze some potential problem areas in detail and to conduct some test points not addressed in this program which may be of concern with incorporation on future aircraft.

Breathing Regulator

The OEAS Breathing Regulator has demonstrated the ability to provide a breathing gas at physiologically acceptable pressure and sufficient flowrate when incorporated on the AV-8A. Outlet pressure results indicate satisfactory operation with minimum inlet pressures anticipated from the eighth stage of the AV-8A, and with maximum inlet pressure limited to 70 psig (with 250 psig to the inlet of the concentrator if the bleed air regulator is removed). Outlet pressures were generally above or below specification with higher or lower inlet pressures, respectively. Also, the regulators have exhibited a tendency to be within specification limits at high inlet pressure (120 psig) at altitude and below specification minimum with low (5 or 15 psig) inlet pressure or be within specification at low inlet pressure and above specification maximum with 120 psig, suggesting shifting "bands" of satisfactory performance.

Of particular concern during the testing program has been the apparent shift (drop, and/or non-repeatability of regulator outlet pressure at altitude, particularly with low inlet pressure. Drops in outlet pressure were experienced twice on each regulator and although having occurred twice with acceleration, the specific causes for aneroid calibration shift are not known, as downward shifts were experienced after endurance testing and after one week of idle storage. Non-repeatability was also evident twice on regulator S/N 11E, with initial and with pre-vibration (post low temperature) outlet pressure testing. The ability of the aneroid assembly to hold calibration with time appears in doubt. No demand valve problems sticking open or closed were experienced throughout the program.

No problems are anticipated with respect to safety pressure if the OEAS regulator is used with the MBU-14/P oxygen mask (MBU-12/P with Navy communications). Reference 27 documents results of a compatibility investigation of the CRU-79/P (mini-reg) with the 14/P, which states a need for limiting safety pressure to a maximum of 1.5 inches of water which will minimize exhalation problems with the combination inhalation/exhalation valve. A lower safety pressure is also preferred by aircrewmen. OEAS regulator safety pressures were typically 1.0 to 1.1 inches of water. The need for restraint in the soft hose has also been stated which, along with the results of reference 3, show that a volume change (stretching) of the hose upon inhalation, followed by a return of the hose to normal form, also make exhalation difficult. Provisions are made through use of the soft hose internal restraint cord to limit stretching to approximately one inch. The need for safety relief within the system is also a possibility as none is incorporated in the combination valve of the 14/P (manufactured to the requirements of MIL-V-27296A (USAF) (14)) nor is any anticipated.

The regulator (in its chest mounted configuration) has also shown excessive noise levels at 3200 and 6400 Hz, a phenomenon also evident with 100% oxygen (miniature) regulators. Raising the specification limit to 95 dB (from 85) at these frequencies is a possibility. However, no noise level problems are anticipated using the personnel hose assembly.

Although the structural integrity of the regulator has been proven with vibration testing, the outlet pressure shifts found when altitude tested after each axis should be addressed further. Initial vendor vibration tests revealed a tendency for outlet pressure to shift downward after vibration and have attributed this to aneroid wear after endurance level vibration, hence, the additional inch of water tolerance placed on minimum specification values. This phenomenon is not considered serious due to (1) the improbability of prolonged endurance level vibration occurring in service and (2) cleaning and readjustments which will become part of scheduled service intervals. The modified East/West bracket is adequate for regulator steadiness in any vibration environment. Some motion is present when installed, however, but is deemed necessary to insure relative ease in installation/removal and provides some vibration attenuation. Initial vendor testing while "hard mounting" the regulator (bolted directly to fixture) revealed an inability of the aneroid assembly to withstand endurance level vibration. To maintain a high confidence level, the regulator should never, in any present or future supply line modification, be mounted directly to the airframe.

To become compatible with the modifications to the aircraft installation (to be discussed later), redesign of the regulator will be accomplished. Internal modifications will be made to provide the capability of supplying approximately 75 lpm at positive pressure with an inlet pressure of 5 psig. This will insure satisfactory operation with lower inlet pressures in the event of excessive pressure drop at sea level static idle conditions. The statement of work for this regulator (now chest mounted) is presented in Appendix B. Provisions are included for insuring satisfactory operation (1) in aircraft which may provide inlet pressures lower than 15 psig at altitude, (2) with standard LOX systems, (3) with the MBU-14/P mask/hose, and (4) with specially selected environmental tests for MIL-STD-810C.

Parallel to this effort, NAVAIRDEVCEN will also initiate exploratory development (6.2) of a fluidic oxygen regulator under the sponsorship of AIR-340B. The effort will attempt to develop a regulator utilizing fluidic technology that is also compatible with the operating parameters of enriched air systems.

Performance Monitor

The performance monitor has demonstrated the ability to provide an adequate warning signal in the event of a drop in oxygen concentration to below anticipated and physiological minimum values. Although some failures discussed previously have arisen due to deficiencies in quality control, three problem areas are evident as a result of laboratory and flight testing. They are:

Temperature

The performance monitor will provide an error in signal output (calibration shift) with any exposure (operating or non-operating) to temperatures below 40°F (4.4°C). This occurs both with convection and with conduction through the monitor baseplate. Although the insulating standoffs added on mounting by the Naval Air Test Center have been proven successful for normal in-flight operation, redesign in this area is necessary. An Engineering Change Proposal (ECP) will attempt to maintain a sensor cavity temperature of 55°F (12.8°C) through resistance heating at ambient temperatures down to -65°F (-54°C), the penalties being an increase in size, weight, and power consumption. Warm up times required after long periods of cold soaks (non-operating) are not yet known and may pose a problem.

Of greater concern has been the calibration shift and press-to-vent test failure after exposure to 185°F (85°C), and is believed to occur with any temperature above 160°F (71°C). While the press-to-vent plunger can utilize a lubricant with a higher temperature rating, some internal modification to the sensor tip may be necessary.

Electromagnetic Interference/System Packaging

The failure of the performance monitor to pass the conducted emissions (CE01 and CE03) and conducted susceptibility (CS02) tests appear to be correctable through incorporation of appropriate filtering on the power supply and return pins in the connector. Of greater concern has been the high susceptibility to radiation (RS03), not providing a warning signal when required, providing a signal when not required, and eventual sensor destruction. With employment of an internal heater, the use of body casing/shielding appears feasible, although the monitor has also shown some failures at low field intensity levels (for equipments located within the aircarft fuselage). Complete redesign is needed in this area before incorporation on-board any carrier based aircraft.

With the redesign of system packaging for improvement of radiated susceptibility, some filter/trap is necessary in the ambient reference/supply gas outlet ports of the aneroid assembly to prevent the entrance of moisture during non-operating humidity exposure or the entrance of dust.

Maintainability

The maintainability deficiency evident during laboratory and flight testing (loosening of the press-to-vent assembly while securing the inlet gas line) is in need of correction through redesign. Normal torque applied to the supply line AN cap can cause system leakage, inadequate flow for normal sensor response and is believed to have caused the press-to-vent failure which resulted in a plunger design change. An adequate means of securing wires and elimination of all epoxy and/or RTV from the electronics card with the module are also desired.

In conclusion, the performance monitor is in need of major redesign. A new contract will provide a performance monitor which will accommodate the problem areas discussed with incorporation of the heater ECP and the appropriate filter/packaging modifications to insure the successful completion of all environmental testing. The Statement of Work for this monitor is presented in Appendix III. Parallel to this effort, NAVAIRDEVCEN will also initiate exploratory development (6.2) of alternate sensing concepts under the sponsorship of AIR-340B. This effort will attempt to develop a monitor which is less susceptible to aircraft environments (no heater, filters, etc. required) than state-of-the-art methods and requires no calibration.

As oxygen concentrator performance will exceed the warning activation levels under operating conditions of the AV-8A, the only conceivable event for warning activation at this time is a concentrator rotary (control) valve stop, which will result in air as the breathing gas. An early warning system, to be used in conjunction with the performance monitor and proposed by NAVAIRTESTCEN would be incorporation of a device for monitoring of pressure surges in the nitrogen exhaust line. This device could also be incorporated in the bleed air inlet line, as any time the rotary v[illegible] tops, pressures in and out of the concentrator will be constant. Activation of a warning light i[illegible]t to the concentrator motor drops to zero is another possibility, but not desired, as a structur[illegible] failure could prevent rotary valve turning while current draw remains normal. This phenomenon was experienced at least once during the vibration program. Thus, the pressure swing concept appears were desirable. A cabin located performance monitor is still necessary, however, to allow warning in the event of failures such as breathing gas supply line leaks, or periods when inlet air temperature may be sufficiently high at altitude to drop oxygen concentrations to warning level but not high enough for high temperature warning activation (above 250° F).

Aircraft Installation

Recent developments in hardware configuration have enabled the highly desired return to the "standard" Navy cockpit configuration. Under a NAVAIRSYSCOM contract with the Stencel Aero Engineering Corporation and the EAST/WEST Industries, a modified RALSA has been developed which improves pressure drop enough to return to the normal breathing gas circuit; i.e., from ship supply through the RALSA, and to a chest mounted regulator. General modifications have included redesign, or "gutting out" of the RALSA manifold, redesign of the four hoses linking ship supply to the breathing regulator with respect to inner diameter and quick disconnects, and improvement of regulator capacity with low inlet pressure. Laboratory testing has verified a performance which even improves the maximum breathing gas capacity deliverable while utilizing alternate 2A (Personnel Hose Assembly). This scheme has resulted in an improved system which eliminates the complexity and interface/support problems of Alternate 2A and its emergency system regulator. Aircraft modification to this configuration is presently on-going with performance verification flight testing to follow. OPEVAL will then be conducted on six AV-8A's incorporating this system.

Although this scheme has shown favorable preliminary results for incorporation on the AV-8A/B/C, detailed analysis is required with respect to bleed air pressure available at ground idle with utilization on future aircraft. Adequate ground level capacity with a two man aircraft (TAV-8) also requires further analysis.

Maximum bleed air pressures available also remain an area of concern. Incorporation of a bleed air regulator was deemed necessary as a means of limiting air flow through the heat exchanger (and therefore temperature). Excessive pressures and/or temperatures, however, become critical at altitude when a high purity gas is required. Although AV-8B design studies show the possibility of bleed air regulator removal due to concentrator location (under the cabin) and lower bleed air

temperatures, it is recommended that this regulator be retained until such time when safety considerations (bleed air pressures to the breathing regulator) reach a high confidence level.

In conclusion, design studies should be initiated on all OEAS candidate aircraft. All flight testing experience (data and installation) complemented with all laboratory performance data should be analyzed in detail to insure an optimized OBOG System.

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APPENDIX A
CONCENTRATOR PERFORMANCE DATA

Altitude (KFT)	Inlet Pressure (PSIG)	Outlet Flow (LPM)	Oxygen Concentration (%)
0	8	5	61.2
		10	40.5
		13.1 (1)	35.6
		18	31.7
		26.2 (3)	28.8
		35	27.0
		50	25.5
		62	24.4
	9.3 (AV-8A Minimum)	5	70.4
		10	45.7
		13.1	38.8
		18	33.9
		26.2	30.1
		35	28.1
		50	26.7
		68	25.0
	13.5 (AV-8A Idle Descent)	5	94.2
		10	67.1
		13.1	53.6
		18	44.7
		26.2	37.5
		35	33.4
		50	30.2
		70	27.8
	28 (AV-8A Maximum)	5	94.3
		10	93.9
		13.1	91.4
		18	76.6
		26.2	58.2
		35	50.0
		50	42.2
		70	36.6
	45	5	94.4
		10	94.0
		13.1	93.1
		18	89.0
		26.2	72.9
		35	59.7
		50	48.4
		70	41.3
	60	5	94.4
		10	94.0
		13.1	93.6
		18.0	89.2
		26.2	75.5
		35	63.5

CONCENTRATOR PERFORMANCE DATA

Altitude (KFT)	Inlet Pressure (PSIG)	Outlet Flow (LPM)	Oxygen Concentration (%)
		50	51.5
		70	43.3
	90	5	94.4
		10	94.1
		13.1	93.8
		18	91.5
		26.2	82.9
		35	71.4
		50	57.2
		70	47.4
10	10	5	93.9
		8.4 (1)	71.2
		9.6 (2)	65.1
		13.1	52.6
		16.8 (3)	46.3
		19.2 (4)	44.1
		26.2	37.5
		30	34.5
	19.9 (AV-8A Minimum)	5	93.7
		8.4	94.3
		9.6	94.2
		13.1	88.4
		16.8	72.8
		19.2	65.2
		26.2	54.4
		35	46.2
		50	38.6
		70	33.5
	24.5 (AV-8A Idle Descent)	5	93.4
		8.4	94.1
		9.6	94.2
		13.1	94.1
		16.8	87.8
		19.2	78.1
		26.2	63.2
		35	53.4
		50	43.8
		70	37.4
	28 (AV-8A Maximum)	5	93.4
		8.4	94.1
		9.6	94.2
		13.1	94.4
		16.8	93.4
		19.2	89.1
		26.2	71.2
		35	58.3

CONCENTRATOR PERFORMANCE DATA

Altitude (KFT)	Inlet Pressure (PSIG)	Outlet Flow (LPM)	Oxygen Concentration (%)
		50	47.6
		70	40.8
	45	5	93.6
		8.4	94.2
		9.6	94.3
		13.1	94.5
		16.8	94.3
		19.2	93.6
		26.2	84.1
		35	69.8
		50	56.2
		70	46.9
	60	5	93.8
		8.4	94.3
		9.6	94.4
		13.1	94.5
		16.8	94.3
		19.2	93.6
		26.2	86.1
		35	73.0
		50	59.1
		70	49.2
20	20	5.4 (1)	93.9
		7.7 (2)	94.3
		10.8 (3)	94.7
		13.1	94.5
		15.4 (4)	93.9
		18	87.8
		26.2	66.6
		35	55.7
		50	45.8
	25.3 (AV-8A Minimum)	5.4	93.7
		7.7	94.3
		10.8	94.7
		13.1	94.7
		15.4	94.5
		18	94.4
		26.2	77.9
		35	64.6
		50	53.0
		70	43.6
	28 (AV-8A Maximum)	5.4	93.7
		7.7	94.3
		10.8	94.7
		13.1	94.7
		15.4	94.5

CONCENTRATOR PERFORMANCE DATA

Altitude (KFT)	Inlet Pressure (PSIG)	Outlet Flow (LPM)	Oxygen Concentration (%)
		18	94.4
		26.2	77.9
		35	64.6
		50	53.0
		70	43.6
	28 (AV-8A Maximum)	5.4	93.7
		7.7	94.3
		10.8	94.7
		13.1	94.7
		15.4	94.5
		18	94.4
		26.2	83.2
		35	70.2
		50	56.7
		70	46.8
	45	5.4	94.0
		7.7	94.3
		10.8	94.7
		13.1	94.7
		15.4	94.5
		18	94.4
		26.2	89.1
		35	78.8
		50	64.3
		70	53.5
	60	5.4	94.3
		7.7	94.4
		10.8	94.7
		13.1	94.7
		15.4	94.5
		18	94.4
		26.2	89.6
		35	82.0
		50	67.9
		70	55.9
30	20	3.2 (1)	92.9
		5	93.5
		6.4 (2.3)	93.7
		10	94.4
		12.8	94.5
		18	94.2
		26.2	83.4
		35	65.2
	25.1	3.2	92.9
		5	93.3
		6.4 (2.3)	93.6
		10	94.3

CONCENTRATOR PERFORMANCE DATA

Altitude (KFT)	Inlet Pressure (PSIG)	Outlet Flow (LPM)	Oxygen Concentration (%)
		12.8	94.5
		18	94.6
		26.2	86.9
		35	71.3
		50	57.4
30	28 (AV-8A Maximum)	3.2	92.9
		5	93.3
		6.4	93.6
		10	94.3
		12.8	94.6
		18	94.7
		26.2	88.5
		35	74.7
		50	60.5
		70	50.6
	45	3.2	93.7
		5	93.9
		6.4	94.1
		10	94.5
		12.8	94.7
		18	94.8
		26.2	91.9
		35	82.2
		50	67.5
		70	56.5
	60	3.2	94.1
		5	94.3
		6.4	94.4
		10	94.7
		12.8	94.8
		18	94.9
		26.2	92.6
		35	85.6
		50	70.7
		70	58.7
40	21.3 (AV-8A Minimum)	2.2	93.1
		4.4	93.5
		5.0	93.5
		10.0	94.5
		13.1	94.7
		18.0	94.8
		26.2	87.9
		35	74.6

CONCENTRATOR PERFORMANCE DATA

Altitude (KFT)	Inlet Pressure (PSIG)	Outlet Flow (LPM)	Oxygen Concentration (%)
	26.7 (AV-8A Idle Descent)	2.2	93.2
		4.4	93.6
		5.0	93.6
		10.0	94.5
		13.1	94.8
		18.0	94.8
		26.2	88.2
		35	76.4
		50	61.5
	28.0 (AV-8A Maximum)	2.2	93.5
		4.4	93.8
		5.0	93.8
		10.0	94.5
		13.1	94.8
		18.0	94.9
		26.2	89.1
		35	77.1
		50	62.9
		70	52.6
	45	2.2	94.1
		4.4	94.3
		5.0	94.3
		10.0	94.8
		13.1	95.0
		18	95.0
		26.2	92.1
		35	84.5
		50	70.0
		70	57.6
	60	2.2	94.7
		4.4	94.7
		5.0	94.7
		10.0	95.0
		13.1	95.0
		18	95.0
		26.2	92.9
		35	85.9
		50	71.7
		70	59.4
50	18.3 (AV-8A Minimum)	2.2 (1)	93.1
		4.4 (2)	93.3
		5.0 (3)	93.3
		10.0 (4)	94.3
		13.1	94.4
		18	94.4

CONCENTRATOR PERFORMANCE DATA

Altitude (KFT)	Inlet Pressure (PSIG)	Outlet Flow (LPM)	Oxygen Concentration (%)
	23.5	2.2	93.5
	(AV-8A Idle Descent)	4.4	93.7
		5.0	93.8
		10.0	94.6
		13.1	94.8
		18	94.9
		26.2	84.8
	28	2.2	94.0
	(AV-8A Maximum)	4.4	94.2
		5.0	94.2
		10	94.7
		13.1	94.8
		18	94.8
		26.2	89.5
		35	79.5
		50	64.4
		70	54.5
	45	2.2	94.6
		4.4	94.6
		5.0	94.6
		10.0	95.0
		13.1	95.0
		18	95.0
		26.2	92.8
		35	84.6
		50	71.7
		70	58.5
	60	2.2	94.8
		4.4	94.9
		5.0	95.0
		10.0	95.0
		13.1	94.9
		18	94.7
		26.2	92.9
		35	86.2
		50	73.2
		70	60.4

(1) One Man Flowrate; Unpressurized Cabin
(2) One Man Flowrate; Pressurized Cabin
(3) Two Man Flowrate; Unpressurized Cabin
(4) Two Man Flowrate; Pressurized Cabin

APPENDIX B

BREATHING REGULATOR STATEMENT OF WORK

a. The Breathing Regulator as presently configured by Physical Configuration Audit: shall be improved to meet the following acceptance requirements:

(1) The present Regulator weight and dimensions shall not be inc ed without approval from NAVAIRDEVCEN.

(2) The Regulator shall be capable of operating with inlet pressures and providing outlet pressures and flowrates to the aircrewman, utilizing the MBU-14/P mask and hose assembly, in accordance with Table II.

TABLE II

Inlet Supply Pressure (PSIG)	Ambient Flow (LPM)	Altitude (Feet)	Outlet Pressure (in H_2O)
5	0 to 75	Sea Level	0.0 to 1.5
8 to 120	0 to 100	Sea Level	0.0 to 1.5
5 to 120	0 to 100	30,000	0.0 to 1.5
5 to 120	0 to 100	34,000	0.0 to 2.7
5 to 120	0 to 100	36,000	3.5 to 5.5
5 to 120	0 to 100	40,000	8.0 to 10.5
5 to 120	0 to 100	45,000	13.0 to 16.0
5 to 120	0 to 100	50,000	16.0 to 20.0

b. Acceptance testing shall be on 100 percent of all deliverable hardware in accordance with contractor test procedure PD1637503 (latest revision) and shall include:

(1) Visual examination.
(2) Outlet pressure test.
(3) Overall leakage test.
(4) Demand valve leakage-outward test.

<u>ITEM 0009 – Breathing Regulator (Improved) Performance and Environmental Verification Tests</u> – The contractor shall provide environmental testing of the Breathing Regulator (Improved) as set forth below:

a. The improved regulator shall pass the environmental tests of Table III in accordance with MIL-STD-810C and meet the performance requirements stated under ITEM 0008, paragraph a above.

b. The improved regulator shall pass the performance tests of Table IV and meet the performance requirements of ITEM 0008, paragraph a.

BREATHING REGULATOR
STATEMENT OF WORK

ITEM 0010 – Refurbishment of Two (2) Verification Test Breathing Regulators (Improved) – The contractor shall refurbish to "as-new" condition two (2) of the Improved Breathing Regulators used for the environmental testing of ITEM 0009.

Table III

BREATHING REGULATOR ENVIRONMENTAL TESTS FROM MIL-STD-810C

Method No. and Test	Procedure No.	Additional Test Conditions
501.1 High Temperature	II	Operate in accordance with Table II with 160°F ambient temperature. Tolerance of $^{+0}_{-1.0}$ in. H_2O added to outlet pressure limits for all inlet pressures. Minimum outlet pressure of 0.0 in. H_2O at sea level to 34000 ft. for all inlet pressures.
502.1 Low Temperature	I	Operate in accordance with Table II with -65° ambient temperature. Tolerance of $^{+1.0}_{-0}$ in. H_2O added to outlet pressure limits for all inlet pressures.
503.1 Temperature Shock	I	Operate in accordance with Table II after exposure to -70°F to 160°F.
504.1 Temperature/ Altitude	I, Equipment Category No. 5	Operate in accordance with Table II. Tolerances for maximum operating temperature shall remain as specified for Method 501.1; tolerances for minimum operating temperature shall be as specified for Method 502.1. At the conclusion of each step specified at altitude, outlet pressures in accordance with Table II to be conducted (from sea level to 50,000 ft.) while maintaining the ambient temperature specified. Maximum non-operating temperature, 185°F.
507.1 Humidity	II	Operate in accordance with Table II after humidity exposure. The inlet port to regulator shall remain capped during humidity exposure.

BREATHING REGULATOR
STATEMENT OF WORK

Table III (Continued)

Method No. and Test	Procedure No.	Additional Test Conditions
513.2 Acceleration	I, (Structural Test)	Operate in accordance with Table II after exposure. Vehicle category-Carrier based aircraft. Maximum G level in all axes.
	II, (Operational Test)	Vehicle category-carrier based aircraft. Maximum G level in all axes. Operate during test with inlet pressure 35 ± 5 psig. Outlet pressure 0 to 1.5 in. H_2O measured during acceleration.

Table IV

PERFORMANCE TESTS FROM MIL-R-81553(AS)

Test	Additional Test Conditions	No. of Test Samples
Demand Valve Leakage	Inlet Pressures of 5 and 120 psig.	3
Body Leakage	Inlet pressure of 70 psig and outlet capped. Bleed flow not to exceed 750 cc/min.	3
Overload	Operate in accordance with Table II after completion.	1
Noise Level	30 psig and 120 psig inlet pressure. Conduct prior to and after completion of all environmental testing on one unit. MBU-14/P mask and hose (GFE).	1
Endurance	Outlet pressure of 0 to 1.5 inches H_2O during test. Operate in accordance with Table II after completion. Demand valve and body leakage conducted after completion.	1
Vibration	Outlet pressure of 0 to 1.5 inches H_2O during test. Operate in accordance with Table II after completion. Demand valve and body leakage conducted after completion.	1
Underwater Breathing	MBU-14/P mask and hose utilized.	1

APPENDIX C

PERFORMANCE MONITOR STATEMENT OF WORK

ITEM 0003 – Oxygen Monitor, Preproduction, Improved – The Contractor shall fabricate eighteen (18) preproduction, improved OBOGS oxygen monitors as set forth below:

a. The oxygen monitor as presently configured by Physical Configuration Audit shall be improved to meet the following performance requirements.

(1) The monitor size and weight shall be increased only to the extent necessary to accommodate an electric heater and control to maintain suitable sensor operating temperature during low temperature operation, and to accommodate additional requirements for salt fog, dust, rain, and EMI protection. NAVAIRDEVCEN approval is required for all dimensional and mass increases.

(2) The monitor shall be capable of operating between an inlet air pressure range of 4 psig to 25 psig, with a flow rate between 0.2 lpm and 1.0 lpm (0.007 cfm to 0.035 cfm) respectively, at ambient temperature and pressure. Flow rate with an inlet pressure of 70 psig shall not exceed 2.0 lpm. The monitor shall be capable of withstanding a static inlet pressure of 75 psig without damage.

(3) The monitor shall be capable of activating an existing remote warning light when the partial pressure of oxygen falls below 220 ± 10 mm Hg (8.66 ± 0.39 in Hg). In the activated mode, the monitor shall be capable of carrying a maximum current of 1 ampere. The monitor shall operate with 28 volt DC power in accordance with MIL-STD-704B.

(4) The hysteresis exhibited between the warning on level and the warning off level (that is, the point at which the light is activated on with decreasing oxygen partial pressure and off with increasing oxygen partial pressure) shall be equivalent to no more than a 20 mm Hg (0.79 in Hg) partial pressure change in oxygen concentration. The same hysteresis condition shall not be exceeded when sea level oxygen concentration activates an on signal until a higher concentration causes an off signal.

(5) Outward leakage with 5 psig internal pressure and the altitude compensation valve sealed shall not exceed 0.010 lpm (0.00035 cfm).

(6) The monitor shall have a press-to-vent button in the inlet port fitting. With 100 percent oxygen supplied at an inlet pressure of 7 ± 1 psig and when holding the press-to-vent button down (open), the decrease in partial pressure of oxygen shall illuminate the warning light (drop to 220 ± 10 mm Hg) within 20 seconds. Upon releasing the button (vent closed), the warning light shall extinguish within 15 seconds.

(7) Operation at altitude – The sensor cavity shall be limited to an altitude of 28,000 ± 400 feet when exposed to any altitude from 28,000 to 50,000 feet. The monitor with 200 ± 10 mm Hg, O_2 partial pressure in sensor cavity, shall activate the warning signal when tested at altitudes of 10,000, 20,000, 28,000, 30,000, 40,000 and 50,000 feet.

PERFORMANCE MONITOR
STATEMENT OF WORK

ITEM 0004 – Oxygen Monitor (Improved) Performance and Environmental Verification Tests – The Contractor shall provide environmental testing of the Oxygen Monitor (Improved) as set forth below:

a. The improved monitor shall pass the environmental tests of Table I in accordance with MIL-STD-810C and meet the performance requirements stated (ITEM 0003 paragraph a.). The performance requirements listed (ITEM 0003, paragraph a.) shall be conducted before each environmental test (as applicable), and shall meet the specified performance requirements after each environmental test. In addition, the monitor shall show no deviation in calibration point beyond specified tolerances (with 100% oxygen) and shall show no structural crack, deformation or distortion after each environmental test. Three (3) of the monitors produced shall be used by the Contractor to perform the testing of Table I in his plant or his designated test facility. The testing shall be monitored periodically by a NAVAIRDEVCEN representative in addition to normal DCASMA inspection.

Table I

OXYGEN MONITOR ENVIRONMENTAL TESTS FROM MIL-STD-810C

Method Number and Test	Procedure No.	Additional Test Condition
501.1 High Temperature	II	Operational test (performance requirements) with 160°F ambient temperature.
502.1 Low Temperature	I	Operational test (performance requirements) with -65°F ambient temperature. Unit shall not be supplied with electrical power or inlet gas when at -70°F storage temperature. After exposure to unpowered low temperature conditions and prior to operational tests, setting of sensor gain shall be permitted.
503.1 Temperature Shock	I	Operational test (performance requirements) after exposure to -70°F to 160°F. Unit shall not be supplied with electrical power or inlet gas during test. After the 24 hour exposure and prior to operational test, setting of sensor gain shall be permitted.

PERFORMANCE OF WORK
STATEMENT OF WORK

Table I (Continued)

Method Number and Test	Procedure No.	Additional Test Condition
504.1 Temperature Altitude	I, Equipment Category 5	With any test at altitude other than sea level, operation at altitude test to be conducted at 28,000, 30,000, 40,000 and 50,000 feet. Maximum operating temperature 160° F. Maximum non-operating temperature 185° F with sensor tip removed. Unit shall not be supplied with electrical power or inlet gas during any non-operating step. After exposure to unpowered low temperature conditions and prior to operational test, setting of sensor gain shall be permitted.
506.1 Rain	II	Inlet port capped during exposure. Unit not energized with gas or power during exposure. Operational tests (performance requirements) conducted after exposure.
507.1 Humidity	II	Inlet port capped during exposure. Unit not supplied with gas or power during humidity exposure. Operational Tests (performance requirements) conducted after exposure.
509.1 Salt Fog	I	Unit not supplied with gas or power during salt fog exposure. Monitor inlet port capped during exposure. Operational tests (performance requirements) conducted after exposure.
510.1 Dust	I	Unit not supplied with gas or power during dust exposure. Monitor inlet port capped during exposure. Operational test performance requirements) conducted after exposure.
513.2 Acceleration	I, (Structural test)	Operational test (performance requirements) conducted after exposure. Vehicle category-carrier based aircraft. Maximum G level in all axes.

PERFORMANCE OF WORK
STATEMENT OF WORK

Table I (Continued)

Method Number and Test	Procedure No.	Additional Test Condition
	II, (Operational test)	Operate, unit supplied with 28 VDC and 100% oxygen. Output voltage shall remain within the specified tolerances during exposure. Vehicle category-carrier based aircraft. Maximum G level in all axes. Operational tests (performance requirements) conducted after exposure.
514.2 Vibration	IA, Equipment Category b.2	Functional level, 1 hour per axis, $W_o = 0.04\ G^2/Hz$. Unit supplied with 28 VDC and 100% oxygen at 25 psig. Output voltage shall remain within specified tolerances during exposure. Endurance level 1 hour per axis, $W_o = 0.2033\ G^2/Hz$. Unit is non-operating condition during endurance test. Operational tests (performance requirements) after all vibration.
516.2 Shock	I	Basic Design test. Peak value 20 G nominal duration 11 ms. Non-operational during exposure. Operational tests (performance requirements) after 18 shocks.
	II	Transit Drop Test. Non-operational during exposure. Operational tests (performance requirements) conducted after drop tests.
518.1 Temperature-Humidity-Altitude	I	Monitor inlet capped during exposure. Unit shall not be supplied with power during exposure. Operational test (performance requirements) conducted after exposure. After exposure to unpowered low temperature conditions and prior to operational test, setting of sensor gain shall be permitted.

PERFORMANCE MONITOR
STATEMENT OF WORK

ITEM 0004 – Oxygen Monitor (Improved Performance and Environmental Verification Tests (cont'd)

b. The improved monitor shall meet the electromagnetic interference (EMI) requirements of MIL-STD-461B for Category A1b of class A1 equipment as measured in accordance with MIL-STD-462. Tests for the following emission and susceptibility requirements shall be conducted:

CE01 Conducted Emissions, Power and Interconnecting Leads, Low Frequency (up to 15 kHz).

CE03 Conducted Emissions, Power and Interconnecting Leads, 0.015 to 50 MHz.

CE07 Conducted Emissions, Power Leads, Spikes, Time Domain.

CS01 Conducted Susceptibility, Power Leads, 30 Hz to 50 kHz.

CS02 Conducted Susceptibility, Power Leads, 0.05 to 400 MHz.

CS06 Conducted Susceptibility, Spikes, Power Leads.

RE01 Radiated Emissions, Magnetic Field, 0.03 to 50 kHz.

RE02 Radiated Emissions, Electric Field, 14 kHz to 10 GHz.

RS02 Radiated Susceptibility, Magnetic Induction Field, Spikes, and Power Frequencies.

RS03 Radiated Susceptibility, Electric Field, 14 kHz to 40 GHz. Field intensity 200 volts/meter.

The tests shall be conducted at sea level in three modes. Mode 1 will test the monitor with the warning light activated (unit supplied with air at 25 psig). Mode 2 will test the monitor with the warning light off (enriched air (35% oxygen) at 25 psig) and mode 3 during switching (on/off) as applicable.

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